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A THERMAL IMAGING SENSOR EVALUATION FACILITY.(U)
JAN 77 D V CAMPBELL, J P JOHNSON, W R MALLORY F33615-73-C-1135
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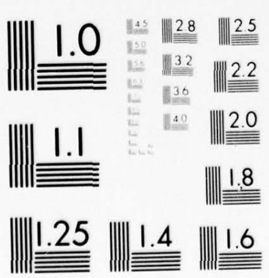

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A THERMAL IMAGING SENSOR EVALUATION FACILITY

SYSTEMS RESEARCH LABORATORIES, INC.
2800 INDIAN RIPPLE ROAD
DAYTON, OHIO 45440

January 1977

TECHNICAL REPORT AFAL-TR-76-223

Interim Report for Period January 1976 through June 1976

AIR FORCE AVIONICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
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This technical report has been reviewed and is approved for publication.

James J. Stewart
Project Engineer

FOR THE COMMANDER

Harold E. Geltmacher, Acting Chief
Electro-Optics & Reconnaissance Branch
Reconnaissance and Weapon Delivery Division

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A facility has been developed for testing and evaluating thermal imaging sensors. The facility employs a differential temperature source imaged by a 12 inch off-axis parabolic mirror collimator. The facility can provide differential temperatures ranging from -20°C to +80°C. Four-bar resolution targets are available from 0.25 cy/mrad to 9.0 cy/mrad. Tests that can be performed include minimum resolvable temperature difference (MRT), signal over

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transfer function (SiTF), modulation transfer function (MTF) and line spread function (LSF), uniformity, and distortion.

FOREWORD

This report was prepared by Systems Research Laboratories, Inc. (SRL), Dayton, Ohio, under Contract No. F33615-73-C-1135. The contract was initiated under Project No. 2004, Task No. 0503. The work was performed under the direction of the Air Force Avionics Laboratory (AFAL), Wright-Patterson Air Force Base, Ohio. Mr. James J. Stewart (AFAL/RWI) was the AFAL Project Manager.

The program was conducted from January 1976 through June 1976. Mr. John Weinhold was the SRL Program Manager and Principal Investigator.

The authors wish to thank Messrs. Larry Shields, Charles Adams, Douglas Mort, and Michael Pershing for their invaluable assistance in this effort. Special contributions by Messrs. Elmer Harbert and Thomas Apple are also gratefully acknowledged. In addition, appreciation is extended to Mr. Donald Sturm, to whom much credit is due for the success of this effort.

This report was submitted by the authors in September 1976.

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INTRODUCTION

BACKGROUND

Projection of future operational capabilities required by the Air Force in tactical reconnaissance indicates a continued and expanded role for thermal (infrared) imaging sensors, such as the forward-looking infrared (FLIR) sensors. To properly evaluate the capabilities and potential of such sensors, either in the developmental stage, or as an instrument of competitive procurement, it is necessary to conduct laboratory and field tests of the sensors. Further, it is extremely desirable that these tests be as nearly standardized as possible in order to permit objective evaluation and comparison of the various candidate sensors. It is toward this end that the Air Force Avionics Laboratory contracted with Systems Research Laboratories, Inc. (SRL) to develop a Thermal Imaging Sensor (TIS) Evaluation Facility, to be located in Building 622 at Wright-Patterson Air Force Base, Ohio. This report describes the development of that facility.

GOAL

The ultimate goal of the ongoing development effort is to establish a fully automated facility for the evaluation of thermal imaging sensors. The block diagram of Figure 1 shows how such a facility will be set up to perform a test such as the minimum resolvable temperature difference (MRT) test or the signal transfer function (SiTF) test. An infrared imaging sensor is set up in the collimated image space of an appropriate infrared target. The temperature differential (ΔT) of the target with respect to the background (ambient) temperature will be controlled by a computer according to instructions entered by the operator through a computer terminal. In addition to the target ΔT, the computer will also control selection of the proper target pattern, as well as perform various other command/control functions. A standard display unit (e.g., a television monitor) compatible with the sensor will be used to display the TIS image. The display unit will be mounted on a numerically controlled XYZ-translation stage whose speed and limits of motion will be controlled by the computer according to programmed instructions. Measurements of the brightness and spatial properties of the displayed image will be made

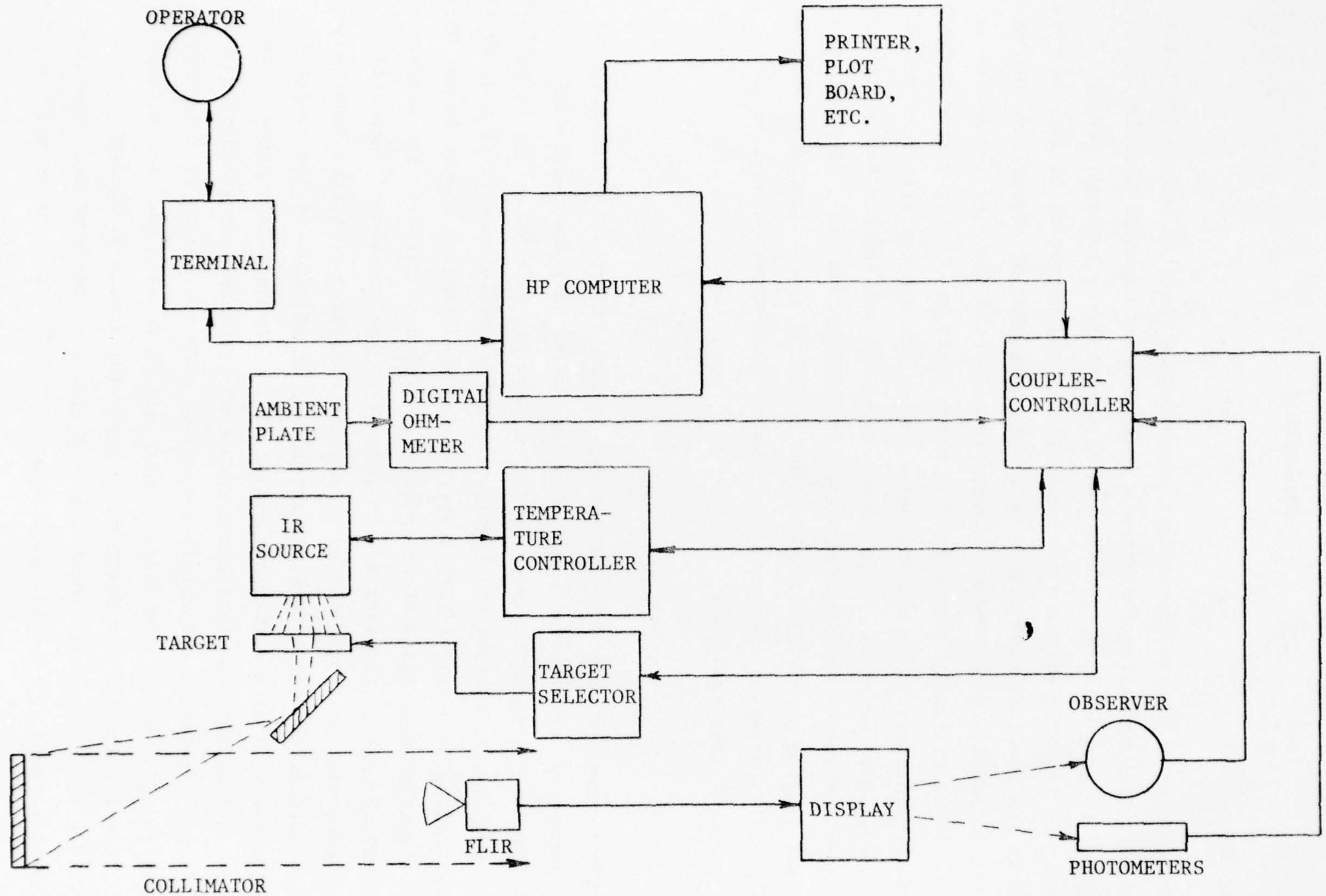

Figure 1. Fully Automated TIS Evaluation Facility

by means of photometers. Certain tests (e.g., MRT) will require that the image be viewed by human observers. Both the human observers and the photometers will provide input data to the computer upon command or appropriate stimulus. This input data will be routed through a coupler-controller to a Hewlett-Packard computer which will perform all necessary computations and output the processed data in a pre-established format.

METHOD OF APPROACH

The approach to achieving a fully automated TIS Evaluation Facility included the planning and research necessary to obtain the required equipment and hardware, especially long lead-time items. Items which were defined and initiated for procurement during this phase included the infrared source and target assembly, the associated temperature controller, optical components (e.g., mirrors and photometer slits), and mounting hardware and translation/rotation assemblies for the folding mirrors, the source and target assembly, and the sensor. In addition, a "mock" system was set up to simulate the characteristics of the temperature controller, temperature measurement devices, and temperature readout instrumentation. This mock system permitted the writing of computer programs for controlling and monitoring the ΔT prior to receipt of the temperature controller and the source/target assembly. A block diagram of the mock system is shown in Figure 2. The temperature controller was simulated by a digitally controlled voltage source and a digital voltmeter; an RC network was used to simulate the characteristics (i.e., the time constant) associated with the thermal source. The ambient temperature was measured by thermistor probes mounted on a metal plate.

The second phase configuration of the TIS Facility implementation is shown in Figure 3, which illustrates the facility in its present status. This partially automated facility incorporates the digitally controlled temperature controller and source/target assembly, although manual selection of target patterns and manual control of the photometer ranging and scanning are still required. In addition, the present configuration employs a modified Lagun milling machine base as an XYZ-translation stage. Although this translation stage can be remotely controlled, control is still manual since numerical control and programmability have not been incorporated.

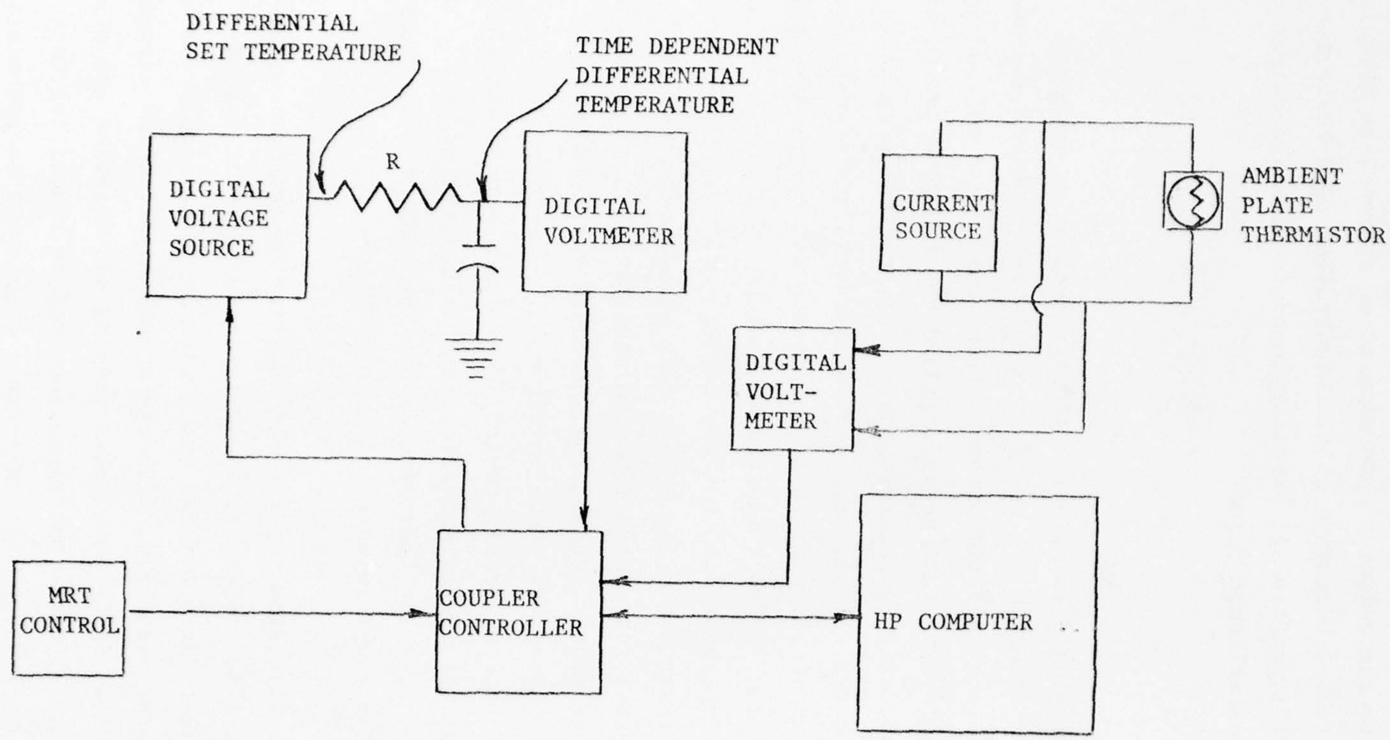

Figure 2. Mock TIS Evaluation Facility

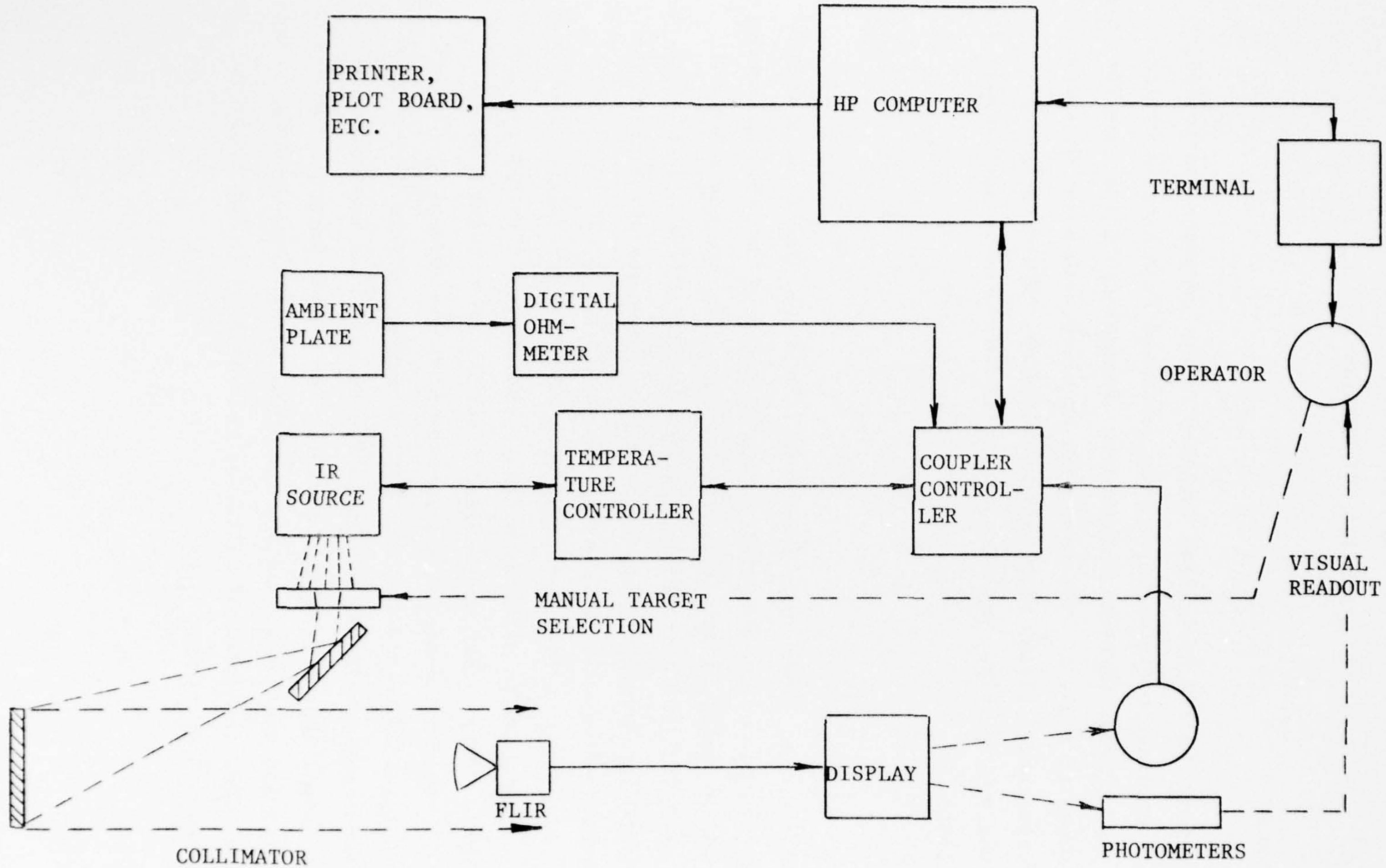

Figure 3. Partially Automated TIS Evaluation Facility

Section II
TECHNICAL DISCUSSION

INFRARED SOURCE

The heart of the TIS Evaluation Facility is the computer-controlled, differential-temperature (infrared) source purchased from Electro-Optical Industries, Inc., Santa Barbara, California. Nominal specifications for this source are shown in Table 1. The source is provided with a set of three interchangeable target plates with various patterns, including four-bar resolution targets, circles, squares, and cross hairs, as well as a slit for MTF measurements.

The Source

The differential temperature source (EOI Model No. 19243) is a thermoelectrically heated and cooled metal plate contained within its own housing. The source plate itself is painted black (Krylon 1602) and has a nominal emissivity of 0.98 (1-25 micrometers), with a useful active area of 4-in. by 4-in. A target (background) plate is held in a rotatable slide mechanism which is mounted externally in front of the source plate and insulated therefrom. A sliding baffle plate, in front of the target plate, also held in place by the rotabable slide mechanism, masks adjacent target patterns from the sensor FOV. Both target and baffle plates are also painted black (Krylon 1602), and have nominal emissivities of 0.98. One of the target slides has a total of twenty-two four-bar resolution targets with nominal spatial frequencies ranging from 0.25 to 9.0 cy/mrad when used with the 103.1875 in. focal length parabolic mirror. The second target slide has a series of circular apertures, and the remaining slide holds squares, cross hairs, and a 0.002 in. (nominal) slit, as well as a space for mounting specially designed apertures.

TABLE 1

SPECIFICATIONS FOR DIFFERENTIAL TEMPERATURE SOURCE

Dimensions:
Source: 8 in. height by 8 in. width by 12 in. depth
Target Plates: 3/8 in. thick by 14-1/4 in. length by 5 in. width

Source Active Area: 3 in. by 3 in.

Source Temperature Range: 00.0 to 99.9°C

Source-Target Differential Temperature Range: -20.00 to +80.00°C

Source Absolute Temperature Control and Readout Accuracy: 0.1°C

Source-Target Differential Temperature Measurement Accuracy:
0.01°C (-20°C to +20°C), 0.1°C (above +20°C)

Source-Target Differential Temperature Control and Readout Accuracy:
0.01°C (-20°C to +20°C), 0.1°C (above +20°C)

Temperature Measurement Rate:
Manual Control: 4/sec
Computer Control: 10/sec
(Upon command to BCD output interface, BCD I/O interface maximum time to select and read any desired temperature must be less than 100 msec)

Differential Temperature Stability: ±0.01°C due to ambient temperature change of 10°C, or power line variation of 1.0% from nominal 115 VAC

Differential Temperature Slew Rate: 0.25°C/sec

Temperature Sensor Time Constant: 1 sec

Source Damping Coefficient: 0.7 ± 0.1 (near critically damped)

Temperature Gradient within Field of View for Both Source and Target Plate: 0.01°C (0° to 20°C), 0.05°C (above 20°C)

Target Plate Temperature: Ambient temperature ± 5°C (Target plate not to be heated or cooled by source to a point where a differential temperature of 80°C cannot be achieved)

Source and Target Plate Emissivity: 0.980 ± 0.005 between 1 and 25 μm wavelength, both identical

Field of View: ≥ 15°

Input Power: 115 VAC ± 10% single phase 60 Hz

Temperature Control

Direct control of the differential temperature source is accomplished by means of the temperature controller (EOI Model No. D2224BS). The operator has the option of controlling either the absolute temperature of the source plate, or the differential temperature between the source and the target plate, in increments as small as 0.01°C. The source plate absolute temperature may be varied from 0°C to 100°C, while the target plate remains at ambient temperature (i.e., cannot be controlled). Accuracy of the temperature control is 0.1°C for the absolute source temperature and 0.01°C for the temperature differential from -20°C to +20°C (0.1°C accuracy above +20°C).

A toggle switch on the front panel of the temperature controller allows selection of either the REMOTE (computer control) or LOCAL (manual control) control modes. With the toggle switch in the LOCAL position, the front panel controls are enabled. Temperature control is accomplished by means of the ABSOLUTE/DIFFERENTIAL switch and the four-decade TEMPERATURE thumbwheel switches.

In the REMOTE mode, the front panel controls are disabled, and control is accomplished through the digital interface by the computer according to programmed instructions. The digital interface is four-decade BCD, with TTL-compatible positive logic in 8-4-2-1 code, plus a sign bit. Data on the input lines is inputted when a "store data" command is received. The "store data" command is typically 400-ms duration, positive true logic which can be reset after 10 μsec by a "busy" signal. The temperature controller returns a "busy" signal after receiving the "store data" command until it has latched the data. The "busy" signal is ≥ 20 μsec positive true logic. BCD input interface pin assignments for temperature control are shown in Tables 2 through 4. Pins 35 through 42 are used for inputting data (refer to Table 2 for pin assignments and associated signals). Pin 34 selects the sign of the inputted data, and pin 20 selects the decades into which the two data bits are to be inputted. Pin 24 is used to indicate that a read or write operation is to be performed, while pins 22 and 23 are used to select source, target or differential temperature for either measurement or control, depending

TABLE 2

BCD INPUT INTERFACE

Pin No.	Code	Record/Program Character
35 36 37 38	1 2 4 8	B0 (Least Significant Bit) or B2
39 40 41 42	1 2 4 8.	B1 or B3 (Most Significant Bit)
34	sign bit	"1" = minus; "0" = plus
20	bit select	"1" = B0, B1; "0" = B2, B3
24	read/write	"1" = read; "0" = write
22 23	select	See Table
25	control	"1" = local; "0" remote
32	store data	"1" = store data
26	ground	
33	busy	"1" = busy

TABLE 3

SELECTION CODES

Pin 22	Pin 23	Function
0	0	Source
0	1	Target
1	0	Differential
1	1	No operation, invalid condition

TABLE 4

BCD OUTPUT INTERFACE

Pin No.	Code	Output Character
29	8	
28	4	Least Significant Bit B0
4	2	
3	1	
31	8	
30	4	B1
6	2	
5	1	
33	8	
32	4	B2
8	2	
7	1	
13	decimal	"1" = 0.01; "0" = 00.1
17	sign bit	"1" = minus; "0" = plus
9	1	Most Significant Bit B3
48	record command	"0" = data available
46	encode	"0" = output data
50	ground	

on the status of pin 24. (See Table 3 for assignments and associated signals for pins 22 and 23.) Pin 25 controls selection of either REMOTE or LOCAL control modes, and its status is determined by the position of the REMOTE/LOCAL toggle switch on the front panel.

Temperature Measurement

Absolute and differential temperatures are measured by means of calibrated platinum resistance thermometers (PRT's) embedded in the source plate and the target slide holder. The PRT outputs are read by the temperature measurement circuitry of the temperature controller. Readout is performed either visually, by means of the four-decade digital panel meter, or by the computer through the digital interface. In the LOCAL mode, the absolute source temperature is displayed on the digital panel meter when the SOURCE/ΔT/TARGET switch is in SOURCE position. Similarly, with the SOURCE/ΔT/TARGET switch in the TARGET position, the digital panel meter displays the absolute target temperature.

With the switch in the ΔT position, the source-target temperature differential is displayed. Readout resolution is 0.1°C for the absolute temperatures, and 0.01°C for the differential temperature from -20°C to +20°C (0.1°C above +20°C).

In the REMOTE mode, the measured temperatures are read from the temperature controller via the digital interface (again four-decade BCD, TTL-compatible, positive true logic, 8-4-2-1 code with sign bit). Pin assignments and associated signals are listed in Table 4. The temperature data is latched onto the output lines by an "encode" command, nominally of 120 μsec duration, negative true logic (TTL-compatible). When an "encode" command is received, the temperature controller sends a "record" command (10 μsec duration, negative true logic [TTL-compatible]), indicating that data is available on the output lines, and the data is then recorded by the computer.

Target Plates

The IR source was supplied with three target plates as described above. Table 5 lists the various target apertures and their nominal sizes. For the four-bar resolution targets, Table 5 also lists the measured mean spatial frequencies of the targets as they were received from the manufacturer.

OPTICS

Optical Configuration

Laboratory testing of long-range optical (including infrared) sensors requires the use of a collimator system which places a virtual image at infinity of the test object to be viewed. Such a collimator system may be either refractive or reflective. The TIS Evaluation Facility uses a collimator system of the latter class, consisting of a 12-inch diameter (103-3/16 in. focal length) off-axis parabolic mirror segment, whose focal plane is displaced by reflecting the optic axis 90 degrees by means of a plane first-surface mirror (Figure 4). When an infrared target, such as one of those described above, is placed in the collimator focal plane and viewed by an infrared

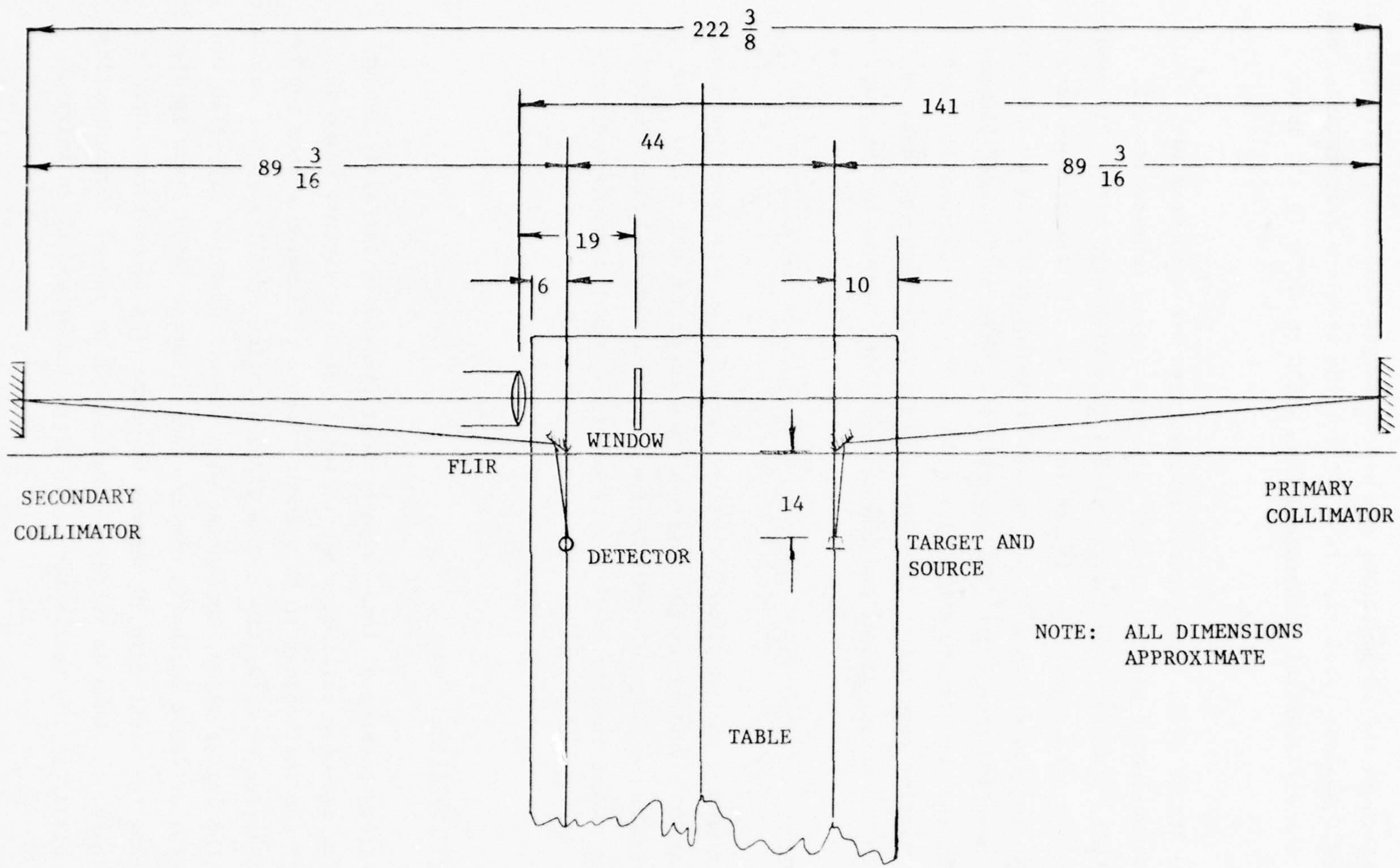

Figure 4. TIS Facility Optical Configuration

TABLE 5

TARGET APERTURE SPECIFICATIONS

1. Four-Bar Targets (7:1 aspect ratio) (Target Plate No. 1)

Target No.	Spatial Frequency (cy/mrad at 103.1875 in.)		
	Nominal	Measured Mean	% Difference
1	0.25	0.2490	-0.40
2	0.50	0.5017	+0.34
3	0.75	0.7489	-0.15
4	1.00	0.9996	-0.04
5	1.25	1.2487	-0.10
6	1.50	1.4951	-0.33
7	1.75	1.7517	+0.10
8	2.00	1.9955	-0.22
9	2.50	2.5009	+0.04
10	3.00	3.0146	+0.49
11	3.50	3.4920	-0.23
12	4.00	3.9901	-0.25
13	4.50	4.4967	-0.07
14	5.00	4.9747	-0.51
15	5.50	5.4832	-0.31
16	6.00	5.9567	-0.79
17	6.50	6.4419	-0.89
18	7.00	6.9706	-0.42
19	7.50	7.4337	-0.88
20	8.00	7.9298	-0.88
21	8.50	8.4624	-0.44
22	9.00	8.9581	-0.47

2. Circular Apertures (Target Plate No. 2)

Target No.	Diameter (in.)	Angular Subtense at 103.1875 in. (mrad)
1	1.816	17.6
2	0.540	5.23
3	0.454	4.40
4	0.381	3.69
5	0.320	3.10
6	0.270	2.62

TABLE 5

TARGET APERTURE SPECIFICATIONS (cont'd)

3. Squares, Cross Hairs, Slit (Target Plate No. 3)

Target	Dimension (in.)	Angular Subtense at 103.1875 in. (mrad)
Large Square	Side - 0.682	6.61
Small Square	Side - 0.170	1.65
Large Cross Hair	Length - 0.682	6.61
	Line Width - 0.040	0.388
Small Cross Hair	Length - 0.170	1.65
	Line Width - 0.010	0.0969
Slit	Height - 0.25	2.42
	Width -	0.0194

sensor, its angular subtense as seen by the sensor is the same as its angular subtense with respect to any point on the surface of the parabolic mirror. To minimize the presence of stray infrared radiation, a rigid baffle system has been constructed and placed around the collimator system. Space is provided, between the rigid baffle and the sensor, to place a special mounting fixture designed to hold window materials in any orientation. A wooden frame placed around this fixture and abutting the rigid baffle allows the use of a blackout cloth to provide additional baffling between the rigid baffle and the sensor.

A second essentially identical collimator system, located in the collimated image space of the first, is used to test transmittance, spectral response, and image spoiling properties of window materials. In this case, an appropriate pattern placed in the focal plane of the first collimator is imaged by the second onto an appropriate detector preceded in the optical path by either a wide-band filter or a narrow-band circular variable filter.

Location of the Sensor in Collimated Image Space

The maximum distance of the sensor to be tested from the collimating mirror can be determined as follows. In Figure 5 the collimator is represented as an off-axis section of an ideal lens. This ideal lens collimates light from a point source at its focal plane into a cylinder of light. The angle that this cylinder of light makes with respect to the optic axis can be determined by extending a ray from the point source through the center of the lens where it would pass through unrefracted. For an extended source, an infinite number of these cylinders of light exist in the collimated image space. For a circular source of radius y, the superposition of these cylinders produces a cone of uniform irradiance whose apex at point T (Figure 5) can be shown to occur at a distance X_c given by

$$X_c = \frac{r_m f}{y}$$

where r_m is the radius of the collimator (i.e., the active portion of the ideal lens) and f is its focal length. For a 12-in. diameter collimator with f = 103.1875 in.,

$$X_c = \frac{619.125}{y} \quad \text{in.}$$

So that the sensor to be tested is uniformly irradiated over its entire entrance aperture, the diameter of the entrance aperture must not be greater than the diameter of the cone of uniform irradiance; thus the larger the entrance aperture, the closer the sensor must be to the collimator for a given size target pattern. The farthest point at which the sensor should be placed from the collimator for a given entrance aperture is represented by point S in Figure 5. The distance $X_o = \overline{RS}$ can be shown to be given by

$$X_o = \frac{(r_m - r_a) f}{y}$$

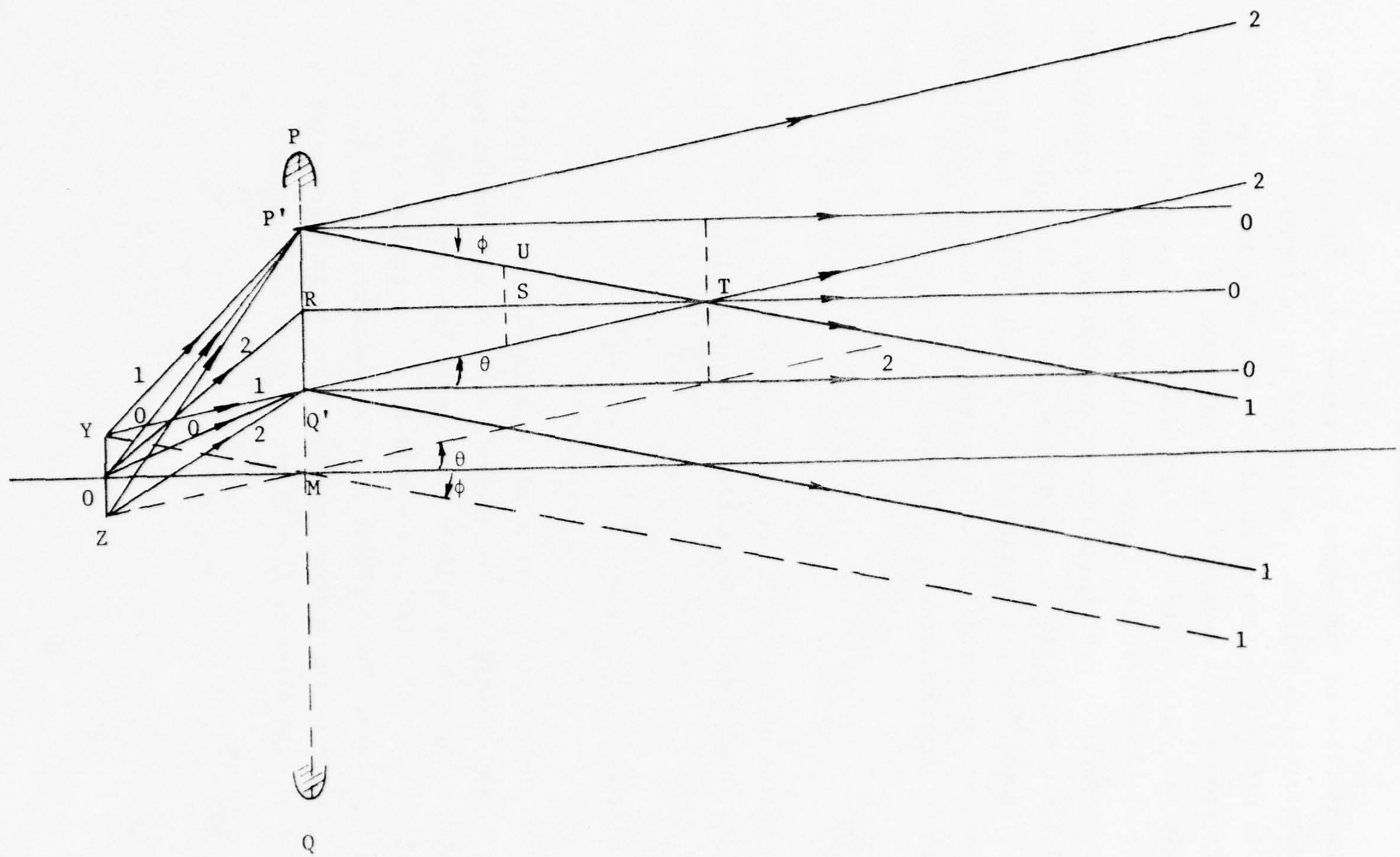

Figure 5. Ideal Lens Model for Off-Axis Parabolic Mirror

where r_a is the radius of the sensor's entrance aperture. For a sensor with a 9-in. diameter entrance aperture, with the values given above for f and r_m,

$$X_o = \frac{154.78}{y} \quad \text{in.}$$

Obstruction of the Uniform Irradiance Region Due to Placement of the Folding Mirror

The plane first surface mirror used to fold the optical path 90 degrees from the optic axis was originally sized to allow the imaging of a maximum 3-in. square target. The largest four-bar target presently in use is 2.0472 in. diagonally. The mirror has been located to permit imaging of targets 2.05 in. or less in diameter. The required placement of this mirror with respect to the parabolic collimating mirror can be determined from Figure 6 using analytic geometry.

The equation of the upper ray from the upper source edge to the upper edge of the collimating mirror is

$$y = x \tan\alpha + 2R_M + D_A$$

where

$$\tan\alpha = \frac{2R_M + D_A - r_s}{f}$$

where α is the angle of the ray with respect to the optic axis, R_M is the radius of the collimating mirror, D_A is the distance of the lower edge of the collimating mirror from the optic axis, r_s is the radius of the target pattern (assuming a circular pattern), and f is the collimator focal length.

The equation of the plane of the folding mirror is

$$y = x + f - D_m$$

where D_m is the distance from the source to the point where this plane intersects the optic axis. The source is located at the point (-f,0).

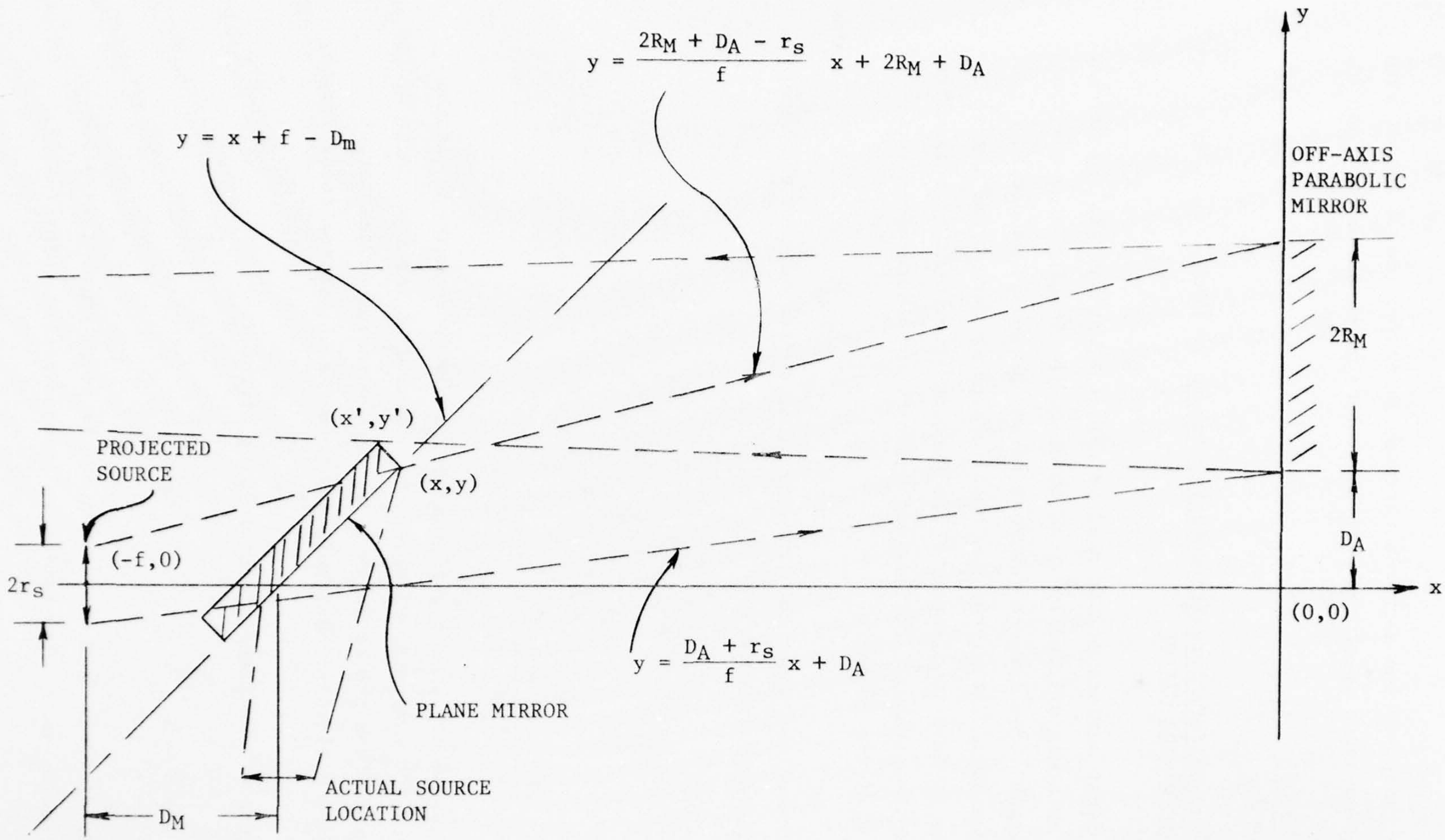

Figure 6. Geometry for Determining Obstruction Due to Plane Folding Mirror

Solving these two equations simultaneously yields the point (x,y) at which the upper edge of the folding mirror should be placed to allow imaging of the largest four-bar target (2.0472 in. diagonally). With $R_M = 6$ in., $r_s = 1.0236$ in., $D_A = 3.0$ in., $D_m = 12$ in., and $f = 103.1875$ in.,

$$\tan\alpha = \frac{2R_M + D_A - r_s}{f} = \frac{12 + 3 - 1.0236}{103.1875} \simeq 0.13545$$

and the two equations above are solved simultaneously to give

$$x = \frac{D_m + r_s}{(1 - \tan\alpha)} - f = \frac{12 + 1.0236}{0.86455} - 103.1875 = - 88.1235$$

and

$$y = \frac{D_m \tan\alpha + r_s}{(1 - \tan\alpha)} = \frac{12(0.13545) + 1.0236}{0.86455} = 3.0640$$

Taking into account the thickness of the mirror substrate ($t = 1.0$ in.) and allowing for a 1/32 in. bevel on the edge of the mirrored surface, the point

$$(x',y') = (-88.809, 3.793)$$

represents the location of the upper rear corner of the mirror substrate.

To determine how much the folding mirror obstructs the region of uniform irradiance, it is noted that the depression of the lower reflected ray with respect to a line from the lower edge of the mirror parallel to the optic axis, at a distance x_p is

$$d = \frac{|x_p|\ r_s}{f}$$

At $|x_p| = 88.809$ in.,

$$d = \frac{88.809(1.0236)}{103.1875} = 0.881 \text{ in.}$$

With respect to the origin,

$$y_d = d + 3.0 \text{ in.} = 3.881 \text{ in.}$$

and

$$y_d - y' = 3.881 - 3.793 = 0.088 \text{ in.}$$

Thus, there is no obstruction of the region of uniform irradiance due to the folding mirror when it is located as shown above.

Effect of the Collimator on Measurement of Optical Transfer Functions

For the purpose of the following analysis, it is again assumed that the collimator can be represented by an ideal lens, although the off-axis character of the real collimator will be ignored. Figure 7 illustrates, in very simplified form, a typical OTF measurement setup.

An approximate point source is collimated by lens L_1. The optical system to be tested (in this case a simple lens), L_2, is placed a distance d behind it and the intensity distribution is measured in plane PP', the focal plane of the test lens. It is important to know what the effects of the collimator lens are on the measurement. The quantity being measured is the modulation transfer function--the modulus of the optical transfer function.[1] The optical transfer function is the Fourier transform of the unit response function. There are several types of unit response functions and optical transfer functions.

In general, we describe optical signals by a complex function,

$$U(\vec{r}) = A(\vec{r})\, e^{i\phi(\vec{r})}$$

considering the one-dimensional case $\vec{r} \to x$ for simplicity, the extension to more dimensions being straightforward. We are interested in properties of

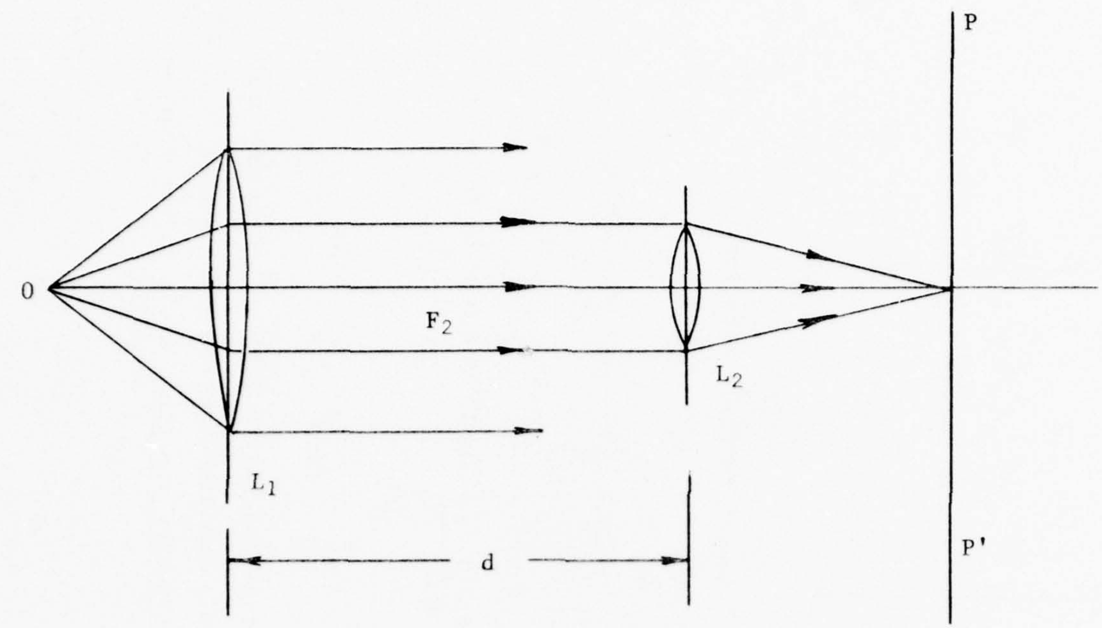

Figure 7. Transfer Function Measurement

the optical signal in a plane α resulting from a signal in plane ξ (see Figure 8) with some optical apparatus in the region (schematically) between ξ and α. We will finally consider the further transfer of the signal to a third plane β.

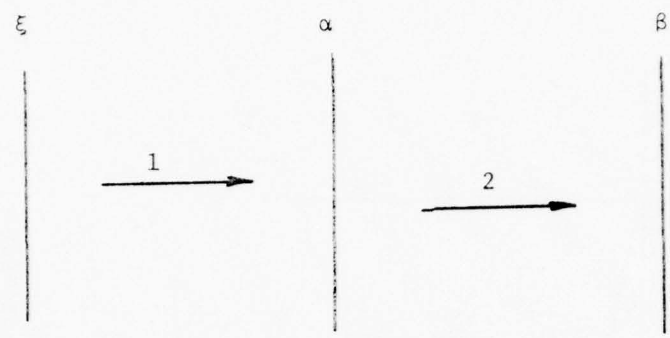

Figure 8. Transfer Function Notation

Different Kinds of Transfer Functions

1. Amplitude or coherent transfer function

The amplitude in the second plane, $U_2(\alpha_0)$, is given in terms of the initial signal, $U_1(\xi)$, by

$$U_2(\alpha_0) = \int U_1(\xi)\ K(\alpha_0-\xi)\ d\xi \tag{1}$$

the integral being carried out over the entire ξ plane. K is the unit amplitude response function, i.e., the signal which would result at α_0 if $U_1(\xi) = \delta(\xi-\xi_0)$. The coherent transfer function, $\tilde{K}(\nu)$, is the Fourier transform of K,

$$\tilde{K}(\nu) \equiv F_\nu[K(\xi)]$$

Also, we can obtain the Fourier transform of U_2 by the convolution theorem, as

$$\tilde{U}_2(\nu) = \tilde{U}_1(\nu)\ \tilde{K}(\nu)$$

2. Mutual intensity transfer function

The mutal intensity, Γ_2, at points α_1 and α_2 in the α plane is the average (time or ensemble for signals obeying the ergodic hypothesis which we always assume) of the product of $U(\alpha_1)$ and $U^*(\alpha_2)$,

$$\Gamma_2(\alpha_1,\alpha_2) \equiv \langle U(\alpha_1)\ U^*(\alpha_2)\rangle$$

where * denotes complex conjugate and < > denotes averaging.

Applying Eq. (1), and interchanging the linear operations of integration and averaging,

$$\Gamma_2(\alpha_1,\alpha_2) = \iint \Gamma_1(\xi_1,\xi_2)\ K(\alpha_1-\xi_1)\ K^*(\alpha_2-\xi_2)\ d\xi_1 d\xi_2 \tag{2}$$

As can be seen by letting

$$\Gamma_1(\xi_1,\xi_2) \equiv \delta(\xi_1-\xi_{01})\ \delta(\xi_2-\xi_{02})$$

the product $H(\gamma_{1,2}) \equiv K(\gamma_1)\ K^*(\gamma_2)$ is the unit response for the mutual intensity. The <u>mutual intensity transfer function</u>, $\tilde{H}(\nu_1,\nu_2)$ is the Fourier transform of the mutual intensity unit response function;

$$\tilde{H}(\nu_1,\nu_2) = F_{\gamma_1\gamma_2}\ [K(\gamma_1)\ K^*(\gamma_2)]$$

The Fourier transform of Γ_2 is given by

$$\tilde{\Gamma}_2(\nu_1,\nu_2) \equiv F[\Gamma_2(\alpha_1,\alpha_2)] = \tilde{\Gamma}_1(\nu_1,\nu_2)\ \tilde{H}(\nu_1,\nu_2) \tag{3}$$

3. Intensity transfer function

Note that $\tilde{H}(\nu_1,\nu_2)$ is not the intensity transfer function. By setting $\alpha_1 = \alpha_2$,

$$\Gamma(\alpha_1,\alpha_1) \equiv I(\alpha_1)$$

but the expression inside the integral(2) does not contain the intensity, $\Gamma(\xi_1,\xi_1)$, but is still the mutual intensity. For the completely incoherent case, if we set $\Gamma_1(\xi_1,\xi_2) = I(\xi_1)\ \delta(\xi_1,\xi_2)$, we have an expression for this extreme (unrealistic) case of no coherence. From Eq. (2), after performing the ξ_2 integral using the delta function,

$$\Gamma(\alpha_1,\alpha_2) = \iint I(\xi_1)\ K(\alpha_1-\xi_1)\ K^*(\alpha_2-\xi_1)\ d\xi_1$$

Now, let $\alpha_1 = \alpha_2$ and we obtain

$$I(\alpha_1) \equiv \Gamma(\alpha_1,\alpha_1) = \int I(\xi_1)\ |K(\alpha_1-\xi_1)|^2\ d\xi_1$$

Thus $|K(\alpha_1-\xi_1)|^2$ is the <u>intensity transfer function</u> for the <u>completely incoherent case</u>.

Cascading of Optical Elements

If more than one optical component is used in series we would like to know how to find the transfer function of the combination, knowing those of the individual elements. The first question to be answered is, which transfer function? Since intensities are the measured quantity, it might seem that the intensity transfer function is appropriate. However this function is only appropriate for completely incoherent light. In the measurements of interest, partial coherence exists, particularly in the (intermediate) α plane in Figure 8. Since we do not measure amplitudes, the amplitude transfer function is not helpful. The mutual intensity transfer function is the proper quantity. As pointed out in Item 3, the measured quantity, which is the intensity (in the β plane of Figure 8 or the plane PP' in Figure 7), can be obtained using the mutual intensity transfer function.

We have, by using Eq. (2) twice,

$$\Gamma_2(\beta_1.\beta_2) = \iint \Gamma_1(\beta_1,\beta_2)\ K_2(\beta_1-\alpha_1)\ K_2^*(\beta_2-\alpha_2)\ d\alpha_1 d\alpha_2$$

$$= \iiiint \Gamma_0(\xi_1,\xi_2)\ K_1(\alpha_1-\xi_1)\ K_1^*(\alpha_2-\xi_2)\ K_2(\beta_1-\alpha_1)\ K_2^*(\beta_2-\alpha_2)\ d\xi_1 d\xi_2 d\alpha_1 d\alpha_2 \qquad (4)$$

where $K_1(\alpha_1-\xi_1)\ K_1^*(\alpha_2-\xi_2)$ transforms from the ξ plane to the α plane, and $K_2(\beta_1-\alpha_1)\ K_2^*(\beta_2-\alpha_2)$ transforms from the α plane to the β plane. Γ_0 is the mutual intensity in the ξ plane.

Fourier transforming,

$$\tilde{\Gamma}_2(\nu_1,\nu_2) \equiv \iint e^{2\pi i(\beta_1\nu_1-\beta_2\nu_2)}\ \Gamma_2(\beta_1,\beta_2)\ d\beta_1 d\beta_2$$

By substituting Eq. (4) and using the convolution theorem, we obtain

$$\tilde{\Gamma}_2(\nu_1,\nu_2) = \tilde{H}_1(\nu_1,\nu_2)\ \tilde{H}_2(\nu_1,\nu_2)\ \tilde{\Gamma}_0(\nu_1,\nu_2)$$

But, from Eq. (3),

$$\tilde{\Gamma}_2(\nu_1,\nu_2) = \tilde{\Gamma}_0(\nu_1,\nu_2)\ \tilde{H}_s(\nu_1,\nu_2)$$

where $\tilde{H}_s$ is the mutual intensity transfer function for the entire system. Thus we have the following rule: the mutual intensity transfer function for a cascaded system is the product of the mutual intensity transfer functions of the components.

Since $\tilde{H}_j = |\tilde{H}_j|\ e^{i\theta_j}$ $(j = 1,2)$ and $\tilde{H}_s = |\tilde{H}_s|\ e^{i\theta}$, we also have

$$|H_s| = |H_1|\ |H_2| \qquad (\text{and } \theta = \theta_1 + \theta_2)$$

So the (mutual intensity) modulation transfer function $|H|$ also follows a product rule.

DeVelis and Parent[2] show for the case of a diffraction-limited lens that

$$\tilde{H} = |K(\nu_1,\nu_2)|^2 = \begin{cases} 1 , & \nu_1,\nu_2 \le a/\lambda f \\ 0 , & \text{otherwise} \end{cases}$$

where a is the lens diameter, λ is the optical wavelength, and f is the focal length. The product of two such functions is of the same form, i.e.,

$$\tilde{H}_s(\nu_1,\nu_2) = \tilde{H}_1\tilde{H}_2 = |K_j(\nu_1,\nu_2)|^2 = \begin{cases} 1 , & \nu_1,\nu_2 \le a_j/\lambda f \\ 0 , & \text{otherwise} \end{cases}$$

where the j^{th} component has the minimum value of a/f of all the lenses, i.e., the maximum f/no.

Comparison of f/Numbers in a Cascaded System

Figure 9 shows a collimator such as that of Figure 7 with a projection of the collimator lens into the aperture space. The half angle of the limiting cone of rays determining the effective f/no. of lens L_1 is

$$\theta_1 = D_1'/b$$

where D_1' is the diameter of L_1', the image of L_1, and b is the distance of L_1' from the second focal point of L_2. L_1' is located a distance C behind L_2. Straightforward geometric optics shows that

$$C = f_2 d/(d-f_2)$$

$$b = f_2^2/(d-f_2)$$

and

$$D_1' = f_2 D_1/(d-f_2). \quad \text{Hence, } \alpha_1 = D_1'/b = D_1/f_2.$$

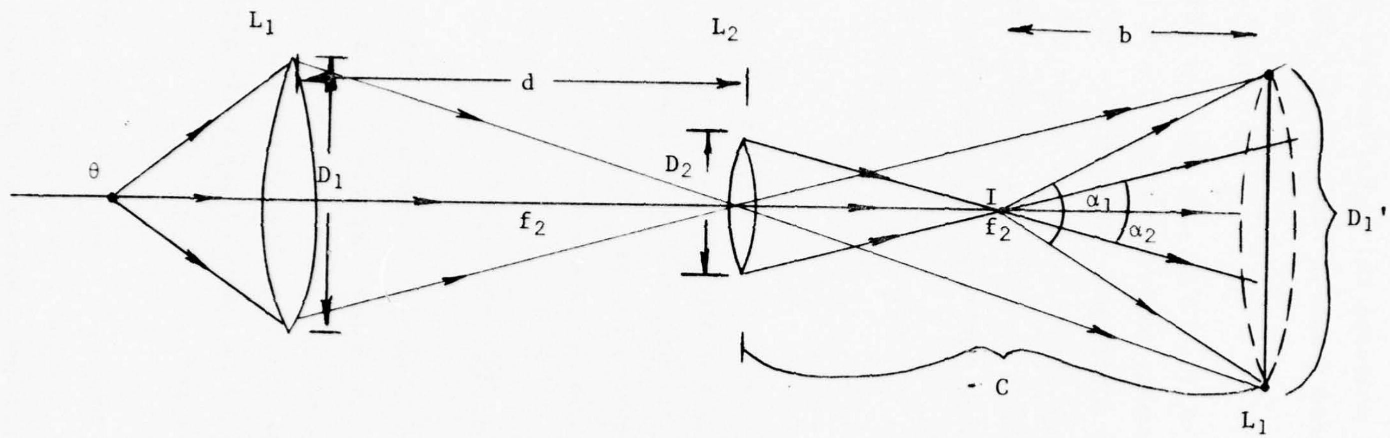

Figure 9. f/Number Comparison of Cascaded Elements

Since α_2, the limiting case for L_2 is $\alpha_2 = D_2/f_2$, a comparison of the effective f/nos.--i.e., essentially α_1 and α_2, reveals that if the collimator is larger in diameter than the lens being measured and is diffraction limited, its effect may be ignored since the cascaded transfer function is determined by the smaller lens.

Figure 10 shows a typical MTF curve of the 12-in. off-axis parabolic collimator (with a 10-in. diameter exit pupil) compared to the theoretical diffraction-limited MTF. This shows that the actual collimator is very close to being diffraction limited and, therefore, its effects on sensor MTF measurements can be safely ignored so long as the sensor's entrance aperture diameter is both smaller than the collimator diameter, and within the uniform irradiance region.

MEASUREMENT CAPABILITIES

The purpose of the TIS Evaluation Facility is the testing and evaluation of thermal imaging sensors. A number of performance tests can be employed in the subjective evaluation and comparison of such sensors, and most of these can be conducted in the present TIS Evaluation Facility with existing equipment. Some of the more useful of these tests are described below.

Minimum Resolvable Temperature Difference (MRTD or MRT)

The MRT is defined as the equivalent blackbody temperature difference (ΔT) between a four-bar resolution target of a given spatial frequency and its background such that the individual bars are just resolvable by an observer.[3] The MRT existence conditions are satisfied when the TIS controls are set, or varied between limits, such that the system is operated quasi-linearly, and is noise-limited rather than contrast-limited.

In the TIS Facility, MRT tests are conducted using the twenty-two four-bar resolution targets ranging from 0.25 cy/mrad to 9.0 cy/mrad. The temperature of the IR source is controlled and measured automatically by a computer program. After a zero-reference ΔT has been established, the ΔT is

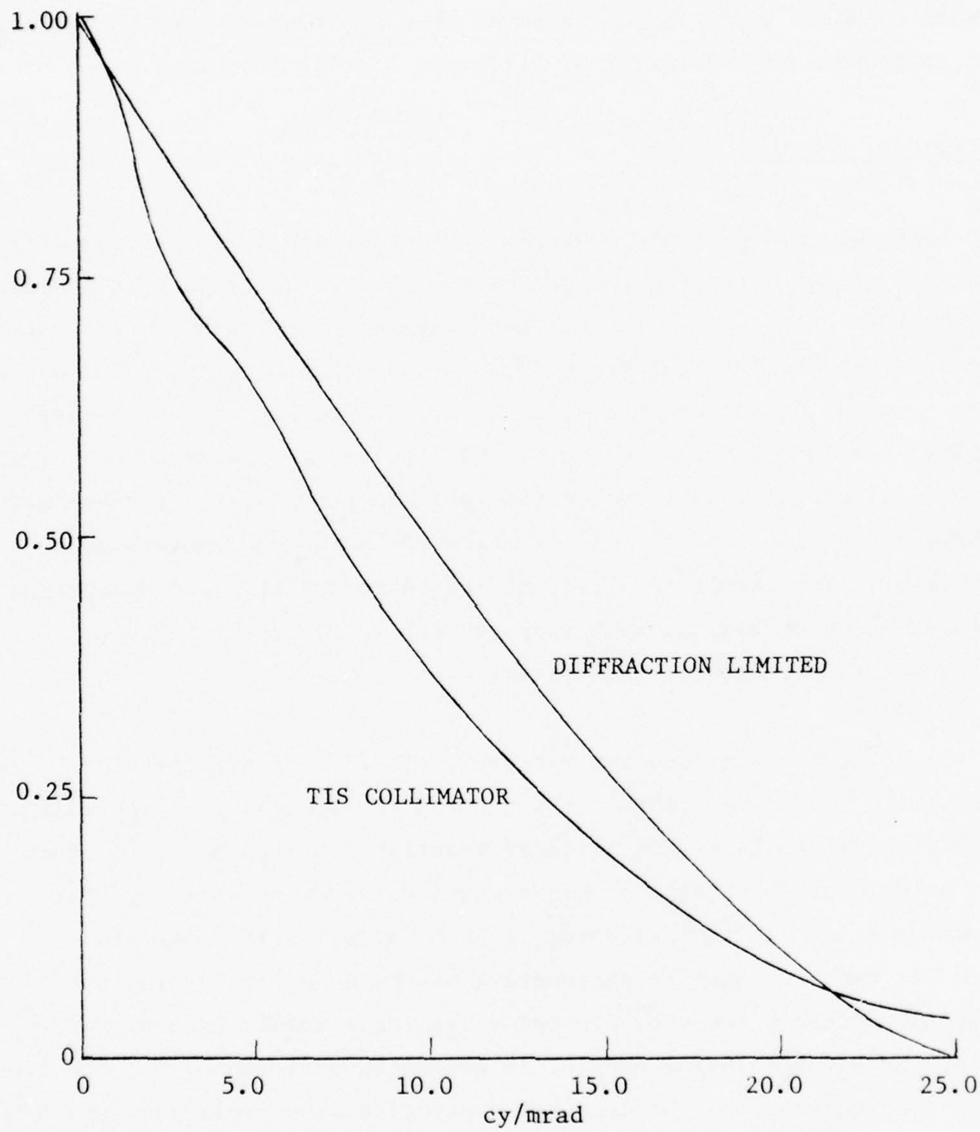

Figure 10. Typical MTF of 12-in. TIS Collimator in 8-14 μm Band versus Diffraction Limited Case

gradually increased from that zero-reference ΔT until the observer can just resolve the four bars of the resolution target, at which point he activates a switch. Activation of this switch causes the computer to cease increasing the ΔT, measure the ΔT and absolute source and target temperatures, and record the data on magnetic tape. The program is then reset at the beginning, allowing the test to proceed with a target of different spatial frequency.

Signal Transfer Function (SiTF)

The SiTF is defined as the photopic luminance output of the system display as a function of the target-to-background temperature difference in a square or circular test pattern.(3) In this test the target pattern and its background are set at the zero reference ΔT, and the brightness and gain controls are set to typical operating settings. A pair of photometers are focused on the display, one on the target pattern, the other on the background. As the temperature differential is increased in small increments, the target-background brightness differential (ΔB) is measured by the photometers as a function of ΔT. The result is a plot of log ΔB versus ΔT. The measurements are repeated for a sufficient number of control settings to adequately characterize the operation of the system.

In the present TIS Evaluation Facility, a series of six circular apertures (with diameters subtending 2.62 mrad to 176 mrad at 103-3/16 in.) are available for use in signal transfer function measurements. For the standard SiTF test, a pattern is chosen which subtends an angle greater than 10 percent of the TIS horizontal field of view. Either Spectra Pritchard or Gamma Scientific photometers may be used for the luminance measurements, although the ones presently available require manual range selection, thereby precluding completely automated performance of SiTF tests. The IR source, however, can be computer-controlled, and amplifiers and A/D converters (and the necessary software) are available to automatically read the photometers upon command.

Sensors with Automatic Contrast Enhancement (ACE)

Some thermal imaging sensors employ a technique called automatic contrast enhancement in which the sensor's level and gain is automatically adjusted according to the average scene contrast. Each object in the scene contributes to the scene average contrast in proportion to its area and ΔT, except that objects whose ΔT's are greater than some set value (e.g., 50°C) are allowed to affect the average scene contrast only as if their ΔT's were equal to the limiting ΔT. The system gain is then controlled so that the maximum output voltage corresponds to a peak-to-peak signal of a given factor (e.g., 4X) times the area-weighted scene contrast.

For sensors with ACE equipment, a test similar to the SiTF test is used to determine how the TIS output signal varies with target size and temperature. Two different tests can be performed. In the first, the target ΔT is held constant while the target area is varied. A series of five circular apertures are available (the same as described above) whose diameters in object space (with the 103.1875 in. focal length collimator) vary from 2.26 mrad to 5.23 mrad such that their areas increase sequentially by a factor of $\sqrt{2}$. In the second test, the target area is held constant while the ΔT is increased.

Line Spread Function (LSF) and Modulation Transfer Function (MTF)

The modulation transfer function is the modulus of the Fourier transform of the line spread function (or one-dimensional impulse response), and describes the relative frequency response of a system output to a unit impulse input. A slit pattern is placed in the collimator focal plane and irradiated by the IR source. The angular subtense of the slit in object space is generally much smaller than the sensor's detector angular subtense. The displayed slit image, as detected by the sensor, is scanned with a photometer outfitted with a narrow slit to measure the line spread function. By taking into proper account the effects of the display (including its spatial characteristics and its inherent MTF) the LSF can be Fourier-transformed by means of a computer to determine the MTF of the sensor itself.

In the present facility, a 58 μm by 6.35 mm etched slit is available, as well as an adjustable slit which can be mounted in a space reserved for special target patterns on one of the target slides. A Gamma Scientific scanning photometer with a 25 μm by 2500 μm slit is used, in conjunction with a 1X or 2.5X objective lens, to measure the line spread function. The LSF can be recorded either on an XY-recorder, or by means of the Biomation Transient Recorder, the latter permitting direct input to the computer.

Uniformity Tests

Another important measurement for thermal imaging sensors is the uniformity of the sensor output when the sensor is viewing a uniform scene (flat field). Uniformity tests can be made over large and small areas. In the large area uniformity test, the point-to-point deviation of the display output is measured with respect to the average output over the entire field of view. Small area uniformity tests measure the variation of the output at a particular point with respect to neighboring areas separated by distances on the order of one equivalent detector angular subtense. Uniformity tests are generally performed by scanning the displayed image with a photometer equipped with a slit aperture. For large area uniformity tests, the required slit size is determined from the criterion that the projected slit width at the display subtends approximately four times the equivalent width of one DAS, and that the slit height is at least five times greater than its width. The width of the slit for the small area uniformity is a factor of 10 smaller than the large slit. Uniformity scans are made in both the horizontal and vertical directions.

In the present facility, a Pritchard photometer is used to scan the display (the photometer is stationary while the display is translated). Presently available slits include a 1.22 mm (6.88 mrad) slit and a 120 μm (0.675 mrad). It is normally required that the scanning velocity must be such that the photometer output (for a given input) is at least 95 percent of the photometer output when the slit is not moving with respect to the display. This condition is satisfied when the MTF due to the scanning motion is 0.95 at the fundamental slit frequency, f_0, or

$$\frac{\sin(\pi f_0 v \Delta t)}{\pi f_0 v \Delta t} = 0.95$$

where v is the scanning velocity, and Δt is effectively the photometer integration time (i.e., time constant). Solving this equation by iterative methods yields

$$v = 0.552/\pi f_0 \Delta t$$

Table 6 shows the maximum scanning velocity for each slit as a function of photometer time constant (range setting).

TABLE 6

MAXIMUM SCANNING VELOCITY OF PHOTOMETER SLITS AS A FUNCTION OF PHOTOMETER TIME CONSTANT

Photometer* Range Setting	Time Constant (ms)	1.22 mm Slit Maximum Scanning Velocity		120 μm Slit Maximum Scanning Velocity	
		(mm/sec)	(in./sec)	(mm/sec)	(in./sec)
10	0.72	595.36	23.439	58.56	2.306
3	2.0	214.33	8.438	21.08	0.830
1	7.2	59.54	2.344	5.856	0.231
0.3	20	21.43	0.844	2.108	0.0830
0.1	72	5.954	0.234	0.586	0.0231
0.03	200	2.143	0.0844	0.211	0.00830
0.01	720	0.595	0.0234	0.059	0.00231

*Spectra Pritchard Photometer Model 1970-PR

Distortion Tests

Another important performance test is the measurement of inherent distortion in the displayed TIS image when the sensor views a pattern of known angular dimensions and/or known angular position. A square aperture (with angular subtense approximately 5 percent of the smallest dimension of the sensor FOV) is placed in the collimator focal plane in the center of the FOV. The horizontal and vertical dimensions of the image on the display are measured with a photometer and the precision translation drive. A scaling factor S_c is computed from

$$S_c = \frac{\text{image size (cm)}}{\text{angular size of target (mrad)}}$$

The square pattern is then replaced by a cross-hair reticle at the same position (and having the same angular subtense). The sensor is then rotated until the reticle is located at a given measurement point, and the horizontal and vertical angles through which the sensor has been rotated are recorded, as are the horizontal and vertical distances of movement of the image on the display. The distortion in either direction is then given by

$$\% \text{ distortion} = 100 \left(\frac{S_c - S}{S}\right)$$

where

$$S = \frac{\text{distance on display (cm)}}{\text{angle of rotation (mrad)}}$$

The present facility has two sets of squares and cross hairs available for use. The angular subtense (at 103.1875 in.) of each of the larger square cross hair is 6.61 mrad; of the smaller ones, 1.65 mrad.

Other Tests

Several other performance tests can be conducted in the TIS Evaluation Facility. Among these are magnification and spectral response. In addition, for those sensors which are TV-compatible, the above tests can be performed

by processing and analyzing the video output signal, using a Biomation Transient Recorder coupled to the computer to look at individual lines of output. Further details on the latter can be obtained from Reference 4.

COMPUTER SOFTWARE AND INTERCONNECTIONS

The following is a description of the operation of the Minimum Resolvable Temperature test program (MRTST). A supplement to this report contains listings and descriptions of the routines involved. Prior to operating the program it is essential that all equipment be properly set up. This equipment includes the coupler controller, temperature controller, and, if the video signals are to be analyzed, the Biomation Transient Recorder, line scanner unit, and line selector unit. The switch settings and cable connections of the coupler controller and temperature controller are contained in Table 7 and Figure 11, respectively. Table 8 and Figure 12 contain the switch settings and cable connections of the Biomation, line scanner, and line selector.

For the following discussion, refer to the appendix. (Example user responses are underlined.) To begin the program the operator must type the following message (page 49):

:PR,MRTST

(It will be assumed from this point on that RETURN/LINEFEED will follow all operator inputs.) The program then begins by typing a title page on the terminal (page 50). The program will proceed when the PAGE button is pressed by the operator, to list an option table (page 51) on the terminal. The program then waits for the operator's choice.

The first option chosen should be number "1". This option initializes parameters for the sensor being tested. The program lists the parameters in groups on the terminal with instructions as in pages 52 through 57. As the example shows, a number is assigned to each parameter. To initialize a given parameter the operator must type its number, a comma, and the new value. Any combination or none at all of the parameters in a group may be

TABLE 7

SWITCH SETTINGS FOR EIO TEMPERATURE CONTROLLER AND HP METER CALIBRATOR

Temperature Controller

Switch	Position
ON/OFF	ON
ABSOLUTE/DIFFERENTIAL	DIFFERENTIAL*
REMOTE/LOCAL	LOCAL **
SOURCE/DELTAT/TARGET	DELTA T *

** After all connections have been made and switches set, set REMOTE/LOCAL to REMOTE.

* When REMOTE/LOCAL is in REMOTE position, these have no effect.

HP 6920B Meter Calibrator

Switch	Position
OFF/AC/DC	DC
RANGE	.1
ONTEST/OFF/ON HOLD	ON HOLD
DIAL SETTING	299

TABLE 8

SWITCH SETTINGS FOR LINE SCANNER/LINE SELECTOR

Sync Separator, Line Scanner

Switch	Position
875/525	dependent on sensor
%. 2/%. 1	%. 1
FIELD 1/ FIELD 2	AS DESIRED
NORMAL/CONTINUOUS	CONTINUOUS

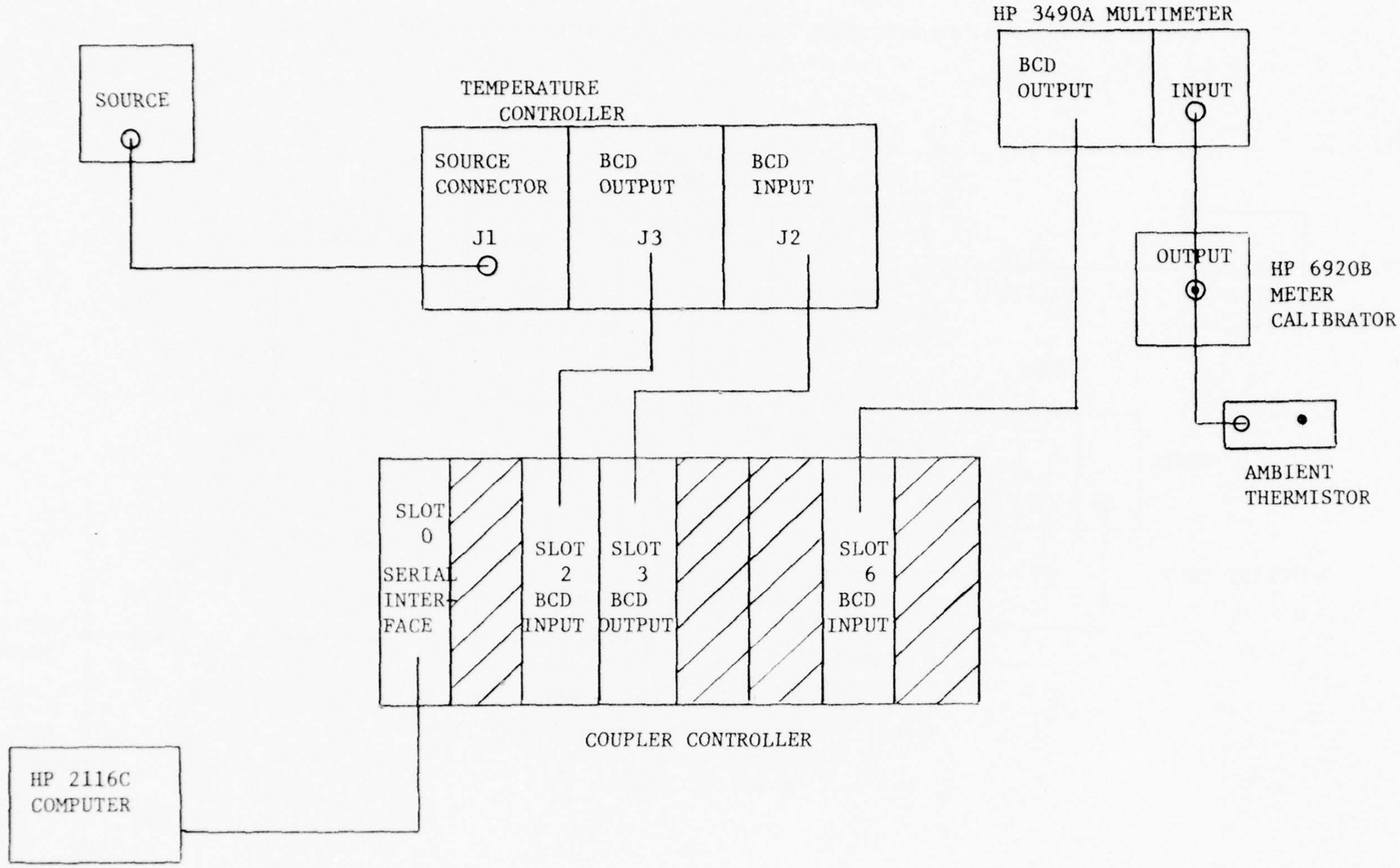

Figure 11. Cable Connections for EOI Temperature Controller and HP Coupler-Controller

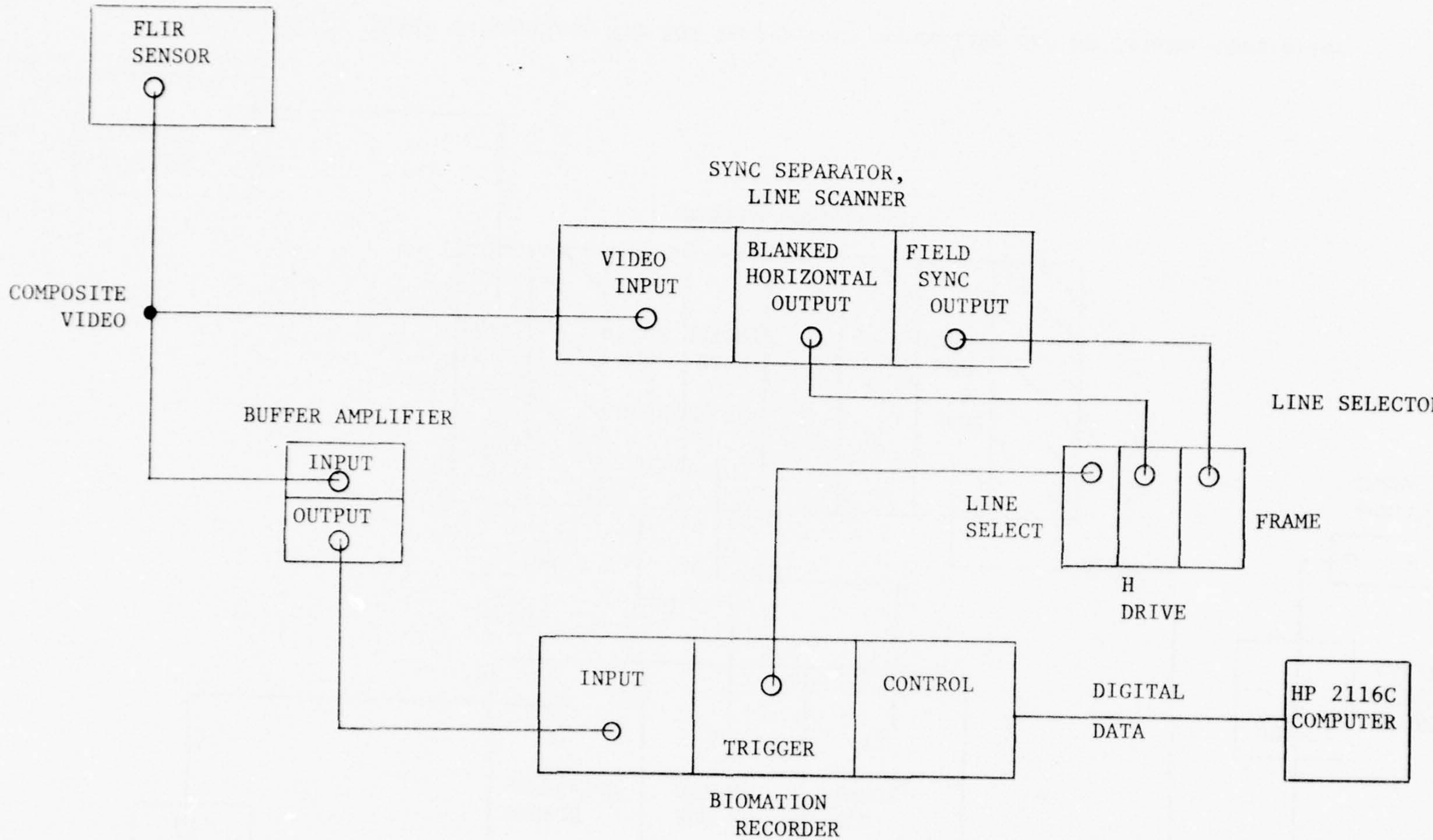

Figure 12. Cable Connections for Biomation, Line Scanner, and Line Selector

initialized. To continue to the next group simply enter a zero, "0". Once the parameters are initialized the program stores the data onto magnetic tape. When the storage is complete the terminal's bell will sound and the option table (page 59) will again be listed on the terminal.

Option 2 should now be chosen by the operator. This option is the first half of the check for the zero-reference point. The temperature controller's ΔT will be decremented by a constant value at regular intervals in time until the observer resolves the lowest frequency target in negative contrast (i.e., the background is hotter than the target). After the operator chooses Option 2 the program requests four inputs (page 61). The first is the absolute value by which ΔT will be incremented or decremented. This value is a real number no smaller than 0.01. The next input is the upper limit which ΔT may reach. The time (in seconds) between each increment or decrement is the third number to be input. It is an integer and must not exceed 32,767. The last number is the value at which ΔT should be set before the test begins.

When the values have been input by the operator, the program pauses for 30 seconds during which time ΔT is set to the initial value just entered. The operator must make sure the MRT button is off during this pause; otherwise, the program will not proceed. When 30 seconds have expired the operator must type GO to start the test. The program proceeds to decrement ΔT until the observer can barely resolve the target and pushes the MRT button. At this moment the ΔT and source and target temperature readings are taken from the temperature controller. The ambient laboratory temperature is also recorded simultaneously. After the data is recorded the operator is asked to update the parameters which were initialized in Option 1. The process of updating the parameters is identical to the method described in the discussion of Option 1. The recorded result and parameters are then stored onto magnetic tape under file names MRT000 through MRT999. The program increments the file name before each storage so that no duplications will occur. If the file number exceeds MRT999 the program will request the operator to input three new characters to replace MRT, thus creating a new set of file names. After the storage is complete, a table of results and the file name under which they are stored is written to the terminal for the operator's inspection

(page 66). The program waits until the operator presses the PAGE button before it lists the option table (page 67) again. The second half of the zero-reference test, Option 3, should now be run. The procedures for operating Option 3 are identical to those just described for Option 2, except that the ΔT is incremented in Option 3 rather than decremented. At the conclusion of Option 3 the option table is again displayed on the terminal.

If the video is to be analyzed during the MRT tests, Option 8 should now be chosen by the operator. The option is necessary to ensure that the system for sampling the video is properly set up, and to obtain the signal's back-porch level for input during the MRT tests. This section requires two integer inputs by the operator: the starting position for sampling, and the number of samples (iterations) to be taken by the Biomation Transient Recorder. The Biomation's display represents 2048 data points of which any 256 can be sampled for S/N measurements. For this option, the starting position should be chosen so that the back-porch level is the minimum point of the 256 points sampled. When the desired number of samples has been averaged and the noise (standard deviation) calculated, the signal and noise data will be plotted on the terminal (Figure 13) and a hard copy will be made, if the Tektronix hard copy unit is connected to the terminal. The minimum value listed under the signal plot (top) is the back-porch level and should be noted. Upon pressing the PAGE button the program will continue and the option table will be displayed.

The operator has two options from which to choose: Option 4 or 5. He should choose Option 4 if the video is to be sampled for signal-to-noise ratio measurements. Option 5 should be chosen if video is not to be analyzed. For operation, both options require the ΔT increment, maximum ΔT, time interval (in seconds) between increments, and the initial value at which ΔT is to be set. These values are the same as those described in the discussion of Options 2 and 3. In addition, for Option 4, required inputs from the operator are the following: the starting point for Biomation sampling, number of samples, line numbers of sampled line, Biomation's voltage range setting, sample range setting, trigger delay, and the signal's back-porch level. The starting position for sampling the Biomation should be chosen such

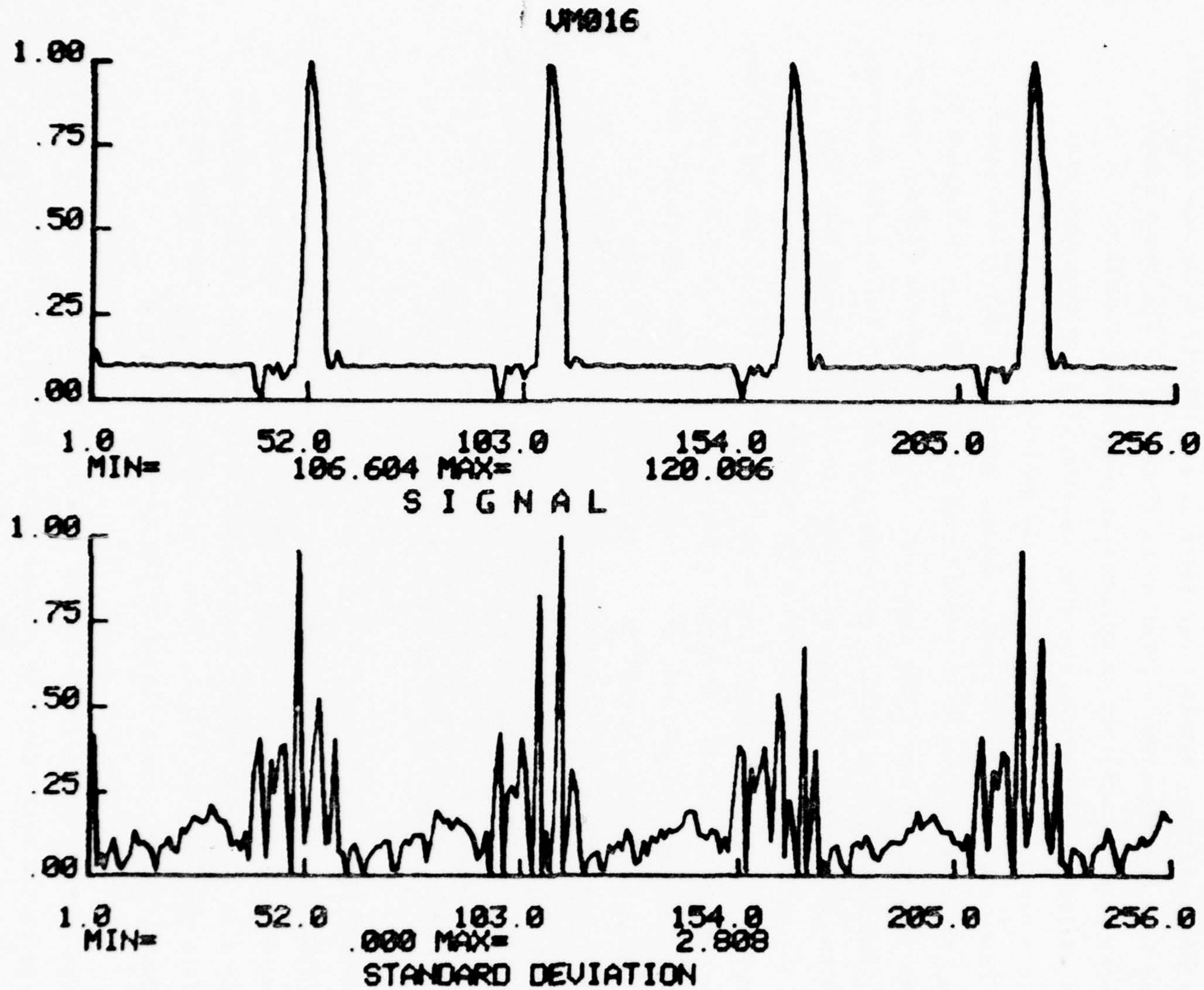

Figure 13. Terminal Plot of Average Signal and Noise (Standard Deviation) as Sampled by Biomation Transient Recorder

that the target is within the 256 points being sampled. The line number is the number of the line of video being sampled and is selected by rotating the thumbwheels on the line selector unit to the desired line number. The voltage range setting, sample range setting, and trigger delay are selectable and read from the Biomation's front panel thumbwheels. The input signal's back-porch level is obtained in Option 8 as previously described. It is usually easiest to choose the starting position of 1, so that the first 256 points are sampled, and simultaneously position the target within these limits using the Biomation's trigger delay. After the appropriate data is entered, the program sets ΔT to the initial value and delays 30 seconds so that the temperature source may stablize. If the difference between this ΔT setting and the previous setting is large, the operator may ask the observer to push the MRT button on. This will cause an extended delay until the button is turned off. When the delay is complete, the program will proceed to increment ΔT at the desired time interval until the MRT button is activated. At that moment the source and target temperatures and ΔT, as well as the laboratory ambient temperature, are recorded. If Option 4 was chosen the Biomation is sampled and a plot of the signal and noise is made on the terminal. When the program continues, the operator is asked to enter the status of the test as being valid or invalid. After this is entered, the operator must update the parameters which were initialized in Option 1. The method of updating them is the same as initializing them. As with the zero reference ΔT, all data is then stored onto magnetic tape.

In addition, the video data is stored in a disc file with a file name corresponding to the magnetic tape file name. For example, if the tape file name is MRT025, the disc file name is VM025. At the completion of the storage a table of the result is displayed on the terminal. The magnetic tape file name is also listed. When the operator presses the PAGE button, the option table is again listed on the terminal.

The operator has several options from which to choose now. If he wishes to go on to the next target he chooses either Option 4 or 5 again. If the test just completed was invalid, then he should choose Option 6. The option will request that the parameters in Option 4 or 5 be reentered, and then the

test proceeds identically as in Option 4 or 5, whichever was just run. If the video data sampled was not good, it may be resampled by choosing Option 7. The starting position and number of iterations are required inputs for this option. Whenever a new observer is to begin testing, Options 1, 2, 3, and, if required, Option 8 should be repeated before starting the MRT tests. When testing is complete, Option 9 should be chosen to end the program.

A sample dialogue between operator and computer for MRTST is contained in the appendix. All operator responses are underlined.

Section III
RECOMMENDATIONS

If the original goal of a fully automated TIS Evaluation Facility is to be realized, some additional work will be necessary, including the acquisition of a remote-control target selection system, and the purchase of new photometers.

REMOTE TARGET SELECTION

The present differential temperature source was supplied with a manually-operated target selection system composed of a rotatable slide holder mounted externally to the source housing, a front baffle slide, and three interchangeable target slides. This target selection system is of a poor mechanical design, and numerous difficulties have been encountered in its use. The slide holder and the slides were manufactured of the same metal (aluminum) to close tolerances. As a result, the slides and the slide holder have a tendency to gall and bind up during operation, a problem which has resulted in several serious delays in a recent test program. A temporary fix has been achieved by tin-plating the mating portions of the slides and slide holder, providing additional lubrication, and frequent cleaning, but the problem remains and is expected to worsen over the long term. At the very least, the slide holder and target slides eventually will have to be replaced or remanufactured.

In addition to the mechanical problems associated with the target selection system, the necessity to manually select and position the targets adds significantly to the time required to conduct certain tests (in particular, the MRT test). Furthermore, the nature of these tests generally requires that they be conducted in the dark, and that a minimum number of personnel be present in the facility during testing.

For the reasons mentioned, a system is needed which allows the desired target to be selected remotely and/or automatically, and which is mechanically reliable. It is thus recommended that a new target selection system be procured. One possible configuration is the large target wheel design previously submitted by SRL.

AUTORANGING PHOTOMETERS

Several of the tests commonly performed on thermal imaging systems employ photometers to measure the brightness of displayed images, either statically or by scanning. Photometers presently available for use in the TIS Evaluation Facility were procured for other purposes, and their usefulness is therefore limited. The Pritchard photometer is an older model which is not equipped with the necessary apertures and does not have an autoranging capability. As a result, display brightness measurements over the entire dynamic range of a sensor requires manual changing of the photometer ranges. The Pritchard photometer also was designed to be used with a meter output, and the vacuum-tube amplifier generates a noisy analogue signal that must be strongly filtered before being input into an A/D converter. The Gamma Scientific photometer, although more nearly compatible with the requirements of the facility, also suffers from the lack of an autoranging capability, as well as the limitations imposed by its maximum field of view not being large enough for most applications involving TV-type displays. It is therefore recommended that action be taken to procure two photometer systems which have an auto-ranging capability, are provided with a set of apertures of optimum size and shape, and are compatible with a digital signal processing system.

COLLIMATOR ALIGNMENT EQUIPMENT

Any time one or more of the optical components of the two collimators are moved or relocated, the entire optical system must be realigned. This is a time-consuming and tedious task, and is aggravated by the lack of proper equipment to perform the task. In the past it has been necessary to spend a significant amount of time locating such equipment, or using equipment which was not designed for such purposes. It is recommended that alignment equipment be acquired and kept permanently in the IR lab for this purpose. Items that are needed include two each penta-prisms, tilt and rotation tables to hold them, small lasers (HeNe), jacks, mounts and leveling tables for the lasers, and a set of pin-hole apertures.

TEMPERATURE SENSOR CALIBRATION

Because the testing of the thermal imaging sensors requires the use of thermal sources, and the accurate calibration of these sources is critical to the evaluation of their performance, it is desirable to have an in-house capability for the calibration of temperature measurement devices such as thermocouples, thermistors, and platinum resistance thermometers. In-house calibration of temperature sensors can eliminate the inconvenience of sending these sensors out for calibration and, in addition, can provide an independent check on the calibration of sensors purchased from the various sources. It is recommended that the necessary equipment be purchased for this purpose.

APPENDIX

Sample dialogue between operator and computer for program MRTST. (All example operator responses are underlined.)


PR,MRTST

```
MMM       MMM    RRRRRRRRRRRR     TTTTTTTTTTTTT
MMMM     MMMM    RRRRRRRRRRRRR    TTTTTTTTTTTTT
MMMM     MMMM    RRR       RRR         TTT
MMMMM   MMMMM    RRR       RRR         TTT
MMMMM   MMMMM    RRR       RRR         TTT
MMM MMMMM MMM    RRRRRRRRRRRRR         TTT
MMM  MMM  MMM    RRRRRRRRRRRR          TTT
MMM       MMM    RRR   RRR             TTT
MMM       MMM    RRR    RRR            TTT
MMM       MMM    RRR     RRR           TTT
MMM       MMM    RRR      RRR          TTT
MMM       MMM    RRR       RRR         TTT


TTTTTTTTTTTTT    EEEEEEEEEEEEE     SSSSSSSSSSS     TTTTTTTTTTTTT
TTTTTTTTTTTTT    EEEEEEEEEEEEE    SSSSSSSSSSSSS    TTTTTTTTTTTTT
     TTT         EEE              SSS       SSS         TTT
     TTT         EEE              SSS                   TTT
     TTT         EEE              SSS                   TTT
     TTT         EEEEEEEE          SSSSSSSSSS           TTT
     TTT         EEEEEEEE           SSSSSSSSSS          TTT
     TTT         EEE                       SSS          TTT
     TTT         EEE                       SSS          TTT
     TTT         EEE              SSS      SSS          TTT
     TTT         EEEEEEEEEEEEE    SSSSSSSSSSSSS         TTT
     TTT         EEEEEEEEEEEEE     SSSSSSSSSSS          TTT
                                           PRESS 'PAGE' TO CONTINUE.
```

```
CHOOSE ONE OF THE FOLLOWING OPTIONS :

     1  INITIALIZE PARAMETERS (MUST BE PERFORMED FIRST)
     2  PERFORM  0 REFERENCE  - DELTA T
     3  PERFORM  0 REFERENCE  + DELTA T
     4  PERFORM MRT WITH NEXT TARGET
     5  PERFORM MRT WITHOUT VIDEO SAMPLING
     6  REPEAT MRT WITH SAME TARGET
     7  RE-SAMPLE BIOMATION
     8  TEST SAMPLE VIDEO WITH BIOMATION
     9  END PROGRAM
```

1

```
  1  SYSTEM
  2  DATE
  3  CONTROLLER
  4  OBSERVER
  5  INDIVIDUALS PRESENT
TO INITIALIZE OR CHANGE A PARAMETER ENTER THE
PARAMETER'S NUMBER, A COMMA, THE NEW VALUE,  AND DEPRESS
THE RETURN/LINEFEED KEYS.  IF NO CHANGES
ARE DESIRED IN THIS GROUP ENTER A ZERO.
? 1,SAMPLE TEST
? 2,25AUG76
? 3,XXXXXXXXXX
? 4,XXXXXXXXXX
? 5,A
? 5,B
? 5,C
? 5,D
? 5,E
? 5,F
? 0
```

```
  6  AMBIENT TEMPERATURE
  7  AMBIENT LIGHTING
  8  COOLING AIR
  9  ALTITUDE
 10  HUMIDITY
TO INITIALIZE OR CHANGE A PARAMETER ENTER THE
PARAMETER'S NUMBER, A COMMA, THE NEW VALUE,  AND DEPRESS
THE RETURN/LINEFEED KEYS.  IF NO CHANGES
ARE DESIRED IN THIS GROUP ENTER A ZERO.
? 6,22.15
? 7,10E-3
? 8,CONTR. FANS
? 9,1700.
? 10,35.
? 0
```

```
   11  TARGET IDENTIFICATION
   12 TARGET ORIENTATION
   13  TARGET LOCATION
   14  WINDOW
   15  ACE
   16  DC RESTORATION
   17  RETICLE
   18  MAGNIFICATION
TO INITIALIZE OR CHANGE A PARAMETER ENTER THE
PARAMETER'S NUMBER, A COMMA, THE NEW VALUE,  AND DEPRESS
THE RETURN/LINEFEED KEYS.  IF NO CHANGES
ARE DESIRED IN THIS GROUP ENTER A ZERO.
? 11,ZZZZZZZZZZ
? 12,45
? 13,ON AXIS
? 14,OUT
? 15,ON
? 16,ON
? 17,OFF
? 18,1:1
? 0
```

```
  19  DISPLAY IDENTIFICATION
  20  DISPLAY BRIGHTNESS
  21  DISPLAY CONTRAST
  22  PWR. SUPPLY FAIL
  23  RECEIVER FAIL
  24  OVERHEAT
  25  NOT READY
TO INITIALIZE OR CHANGE A PARAMETER ENTER THE
PARAMETER'S NUMBER, A COMMA, THE NEW VALUE,  AND DEPRESS
THE RETURN/LINEFEED KEYS.  IF NO CHANGES
ARE DESIRED IN THIS GROUP ENTER A ZERO.
? 19,XXXXXXXXXX
? 20,2.15
? 21,3.45
? 22,OFF
? 23,OFF
? 24,OFF
? 25,OFF
? 0
```

```
  26  ON-STANDBY-OFF SWITCH
  27  POLARITY
  28  GAIN
  29  LEVEL
  30  FOV
  31  FOCUS
  32  SYNC
  33  DEROTATION
TO INITIALIZE OR CHANGE A PARAMETER ENTER THE
PARAMETER'S NUMBER, A COMMA, THE NEW VALUE,  AND DEPRESS
THE RETURN/LINEFEED KEYS.  IF NO CHANGES
ARE DESIRED IN THIS GROUP ENTER A ZERO.
? 26,ON
? 27,WHITE-HOT
? 28,4.23
? 29,2.54
? 30,NFOV
? 31,6.23
? 32,INTERNAL
? 33,5.23
? 0
```

```
  34  RECEIVER ETM
  35  PWR. SUPPLY ETM
  36  GRAY SCALE
TO INITIALIZE OR CHANGE A PARAMETER ENTER THE
PARAMETER'S NUMBER, A COMMA, THE NEW VALUE,  AND DEPRESS
THE RETURN/LINEFEED KEYS.  IF NO CHANGES
ARE DESIRED IN THIS GROUP ENTER A ZERO.
? 34,2435.654
? 35,4325.234
? 36,OFF
? 0
```

STORING DATA ON MAG. TAPE

PLEASE WAIT FOR BELL BEFORE PROCEEDING.

PRESS 'PAGE' TO CONTINUE.

```
CHOOSE ONE OF THE FOLLOWING OPTIONS :

     1  INITIALIZE PARAMETERS (MUST BE PERFORMED FIRST)
     2  PERFORM  0 REFERENCE  - DELTA T
     3  PERFORM  0 REFERENCE  + DELTA T
     4  PERFORM MRT WITH NEXT TARGET
     5  PERFORM MRT WITHOUT VIDEO SAMPLING
     6  REPEAT MRT WITH SAME TARGET
     7  RE-SAMPLE BIOMATION
     8  TEST SAMPLE VIDEO WITH BIOMATION
     9  END PROGRAM

2
```

```
 000    RRRR  EEEEE FFFFF EEEEE RRRR  EEEEE N   N  CCC  EEEEE
0  00   R   R E     F     E     R   R E     NN  N C   C E
0 0 0   RRRR  EEE   FFF   EEE   RRRR  EEE   N N N C     EEE
00  0   R  R  E     F     E     R  R  E     N  NN C   C E
 000    R   R EEEEE F     EEEEE R   R EEEEE N   N  CCC  EEEEE


                    DDDD  EEEEE L     TTTTT  AAA   TTTTT
                    D   D E     L       T   A   A    T
            ======= D   D EEE   L       T   AAAAA    T
                    D   D E     L       T   A   A    T
                    DDDD  EEEEE LLLLL   T   A   A    T
```

PRESS 'PAGE' TO CONTINUE.

```
ENTER THE 'ABSOLUTE' VALUE BY WHICH DELTA T WILL
     BE INCREMENTED OR DECREMENTED.  .01

ENTER THE MAXIMUM VALUE WHICH DELTA T MAY REACH.  10.0

HOW MUCH TIME (IN SECONDS) SHOULD THERE BE BETWEEN
     INCREMENTS OR DECREMENTS ?  30

TO WHAT INITIAL VALUE WOULD YOU LIKE DELTA T SET ?  00.00
```

```
WHILE DELTA T IS BEING SET, PLEASE MAKE SURE
  THAT THE MRT BUTTON IS OFF AND WAIT FOR THE BELL
  BEFORE PROCEEDING.

     NOTE:
PROGRAM WILL NOT PROCEED IF MRT BUTTON IS ON.
```

```
TEST WILL BEGIN WHEN YOU TYPE 'GO'
 FOLLOWED BY RETURN/LINEFEED.  GO
```

NOTE TO READER: THE STEPS SHOWN ON PAGES A-4 THROUGH A-9 ARE REPEATED HERE FOR PARAMETER UPDATING.

STORING DATA ON MAG. TAPE

PLEASE WAIT FOR BELL BEFORE PROCEEDING.

PRESS 'PAGE' TO CONTINUE.

```
THE RESULTS ARE :

        AMBIENT TEMPERATURE        =   21.85
        INITIAL DELTA T            =    -.02
        0 REFERENCE DELTA T        =     .00
        TARGET TEMPERATURE         =   21.9
        SOURCE TEMPERATURE         =   21.8
        MRT                        =    -.03
        MRT CORRECTED, OFFSET      =     .00
        MRT CORRECTED, COLL.       =     .00
    ELAPSED TIME =  0 HRS   0 MIN   9 SEC

    DATA STORED IN MAG. TAPE FILE - MRT525

                                           PRESS 'PAGE' TO CONTINUE.
```

```
CHOOSE ONE OF THE FOLLOWING OPTIONS :

     1  INITIALIZE PARAMETERS (MUST BE PERFORMED FIRST)
     2  PERFORM  0 REFERENCE  - DELTA T
     3  PERFORM  0 REFERENCE  + DELTA T
     4  PERFORM MRT WITH NEXT TARGET
     5  PERFORM MRT WITHOUT VIDEO SAMPLING
     6  REPEAT MRT WITH SAME TARGET
     7  RE-SAMPLE BIOMATION
     8  TEST SAMPLE VIDEO WITH BIOMATION
     9  END PROGRAM

3
```

```
 000    RRRR  EEEEE FFFFF EEEEE RRRR  EEEEE N   N  CCC  EEEEE
0  00   R   R E     F     E     R   R E     NN  N C   C E
0 0 0   RRRR  EEE   FFF   EEE   RRRR  EEE   N N N C     EEE
00  0   R  R  E     F     E     R  R  E     N  NN C   C E
 000    R   R EEEEE F     EEEEE R   R EEEEE N   N  CCC  EEEEE


           +    DDDD  EEEEE L     TTTTT  AAA   TTTTT
           +    D   D E     L       T   A   A    T
        +++++++ D   D EEE   L       T   AAAAA    T
           +    D   D E     L       T   A   A    T
           +    DDDD  EEEEE LLLLL   T   A   A    T
```

PRESS 'PAGE' TO CONTINUE.

```
ENTER THE 'ABSOLUTE' VALUE BY WHICH DELTA T WILL
     BE INCREMENTED OR DECREMENTED.  .01

ENTER THE MAXIMUM VALUE WHICH DELTA T MAY REACH.  10.00

HOW MUCH TIME (IN SECONDS) SHOULD THERE BE BETWEEN
     INCREMENTS OR DECREMENTS ?  30

TO WHAT INITIAL VALUE WOULD YOU LIKE DELTA T SET ?  00.00
```

```
WHILE DELTA T IS BEING SET, PLEASE MAKE SURE
  THAT THE MRT BUTTON IS OFF AND WAIT FOR THE BELL
  BEFORE PROCEEDING.

     NOTE:
PROGRAM WILL NOT PROCEED IF MRT BUTTON IS ON.
```

```
TEST WILL BEGIN WHEN YOU TYPE 'GO'
FOLLOWED BY RETURN/LINEFEED.  GO
```

NOTE TO READER: THE STEPS SHOWN ON PAGES A-4 THROUGH A-9 ARE REPEATED HERE FOR PARAMETER UPDATING.

STORING DATA ON MAG. TAPE

PLEASE WAIT FOR BELL BEFORE PROCEEDING.

PRESS 'PAGE' TO CONTINUE.

```
THE RESULTS ARE :

        AMBIENT TEMPERATURE       =   21.85
        INITIAL DELTA T           =    -.03
        0 REFERENCE DELTA T       =     .00
        TARGET TEMPERATURE        =   21.9
        SOURCE TEMPERATURE        =   21.9
        MRT                       =     .03
        MRT CORRECTED, OFFSET     =     .00
        MRT CORRECTED, COLL.      =     .00
    ELAPSED TIME =  0 HRS   0 MIN  29 SEC

    DATA STORED IN MAG. TAPE FILE - MRT526

                                        PRESS 'PAGE' TO CONTINUE.
```

```
CHOOSE ONE OF THE FOLLOWING OPTIONS :

     1  INITIALIZE PARAMETERS (MUST BE PERFORMED FIRST)
     2  PERFORM  0 REFERENCE  - DELTA T
     3  PERFORM  0 REFERENCE  + DELTA T
     4  PERFORM MRT WITH NEXT TARGET
     5  PERFORM MRT WITHOUT VIDEO SAMPLING
     6  REPEAT MRT WITH SAME TARGET
     7  RE-SAMPLE BIOMATION
     8  TEST SAMPLE VIDEO WITH BIOMATION
     9  END PROGRAM

5
```

ENTER THE 'ABSOLUTE' VALUE BY WHICH DELTA T WILL
BE INCREMENTED OR DECREMENTED. .01

ENTER THE MAXIMUM VALUE WHICH DELTA T MAY REACH. 10.00

HOW MUCH TIME (IN SECONDS) SHOULD THERE BE BETWEEN
INCREMENTS OR DECREMENTS ? 20

TO WHAT INITIAL VALUE WOULD YOU LIKE DELTA T SET ? 00.00

```
WHILE DELTA T IS BEING SET, PLEASE MAKE SURE
  THAT THE MRT BUTTON IS OFF AND WAIT FOR THE BELL
  BEFORE PROCEEDING.

     NOTE:
PROGRAM WILL NOT PROCEED IF MRT BUTTON IS ON.
```

```
TEST WILL BEGIN WHEN YOU TYPE 'GO'
FOLLOWED BY RETURN/LINEFEED.  GO
```

NOTE TO READER: THE STEPS SHOWN ON PAGES A-4 THROUGH A-9 ARE REPEATED HERE FOR PARAMETER UPDATING.

IS THIS TEST VALID OR INVALID ? VALID

STORING DATA ON MAG. TAPE

PLEASE WAIT FOR BELL BEFORE PROCEEDING.

PRESS 'PAGE' TO CONTINUE.

```
THE RESULTS ARE :

        AMBIENT TEMPERATURE       =   21.84
        INITIAL DELTA T           =    -.03
        0 REFERENCE DELTA T       =     .00
        TARGET TEMPERATURE        =   21.9
        SOURCE TEMPERATURE        =   21.9
        MRT                       =     .08
        MRT CORRECTED, OFFSET     =     .08
        MRT CORRECTED, COLL.      =     .07
     ELAPSED TIME =  0 HRS   0 MIN  56 SEC

     DATA STORED IN MAG. TAPE FILE - MRT527

                                           PRESS 'PAGE' TO CONTINUE.
```

```
CHOOSE ONE OF THE FOLLOWING OPTIONS :

        1  INITIALIZE PARAMETERS (MUST BE PERFORMED FIRST)
        2  PERFORM  0 REFERENCE  - DELTA T
        3  PERFORM  0 REFERENCE  + DELTA T
        4  PERFORM MRT WITH NEXT TARGET
        5  PERFORM MRT WITHOUT VIDEO SAMPLING
        6  REPEAT MRT WITH SAME TARGET
        7  RE-SAMPLE BIOMATION
        8  TEST SAMPLE VIDEO WITH BIOMATION
        9  END PROGRAM

5
```

```
ENTER THE 'ABSOLUTE' VALUE BY WHICH DELTA T WILL
     BE INCREMENTED OR DECREMENTED.  .01

ENTER THE MAXIMUM VALUE WHICH DELTA T MAY REACH.  10.00

HOW MUCH TIME (IN SECONDS) SHOULD THERE BE BETWEEN
     INCREMENTS OR DECREMENTS ?  20

TO WHAT INITIAL VALUE WOULD YOU LIKE DELTA T SET ?  0.00
```

```
WHILE DELTA T IS BEING SET, PLEASE MAKE SURE
  THAT THE MRT BUTTON IS OFF AND WAIT FOR THE BELL
  BEFORE PROCEEDING.

     NOTE:
PROGRAM WILL NOT PROCEED IF MRT BUTTON IS ON.
```

```
TEST WILL BEGIN WHEN YOU TYPE 'GO'
FOLLOWED BY RETURN/LINEFEED.  GO
```

NOTE TO READER: THE STEPS SHOWN ON PAGES A-4 THROUGH A-9 ARE REPEATED HERE FOR PARAMETER UPDATING.

IS THIS TEST VALID OR INVALID ? VALID

THE RESULTS ARE :

AMBIENT TEMPERATURE	=	21.86
INITIAL DELTA T	=	-.02
0 REFERENCE DELTA T	=	.00
TARGET TEMPERATURE	=	21.8
SOURCE TEMPERATURE	=	21.9
MRT	=	.13
MRT CORRECTED, OFFSET	=	.13
MRT CORRECTED, COLL.	=	.12

ELAPSED TIME = 0 HRS 0 MIN 50 SEC

DATA STORED IN MAG. TAPE FILE - MRT528

PRESS 'PAGE' TO CONTINUE.

AD-A037 411 SYSTEMS RESEARCH LABS INC DAYTON OHIO F/G 17/5
A THERMAL IMAGING SENSOR EVALUATION FACILITY.(U)
JAN 77 D V CAMPBELL, J P JOHNSON, W R MALLORY F33615-73-C-1135
UNCLASSIFIED AFAL-TR-76-223 NL

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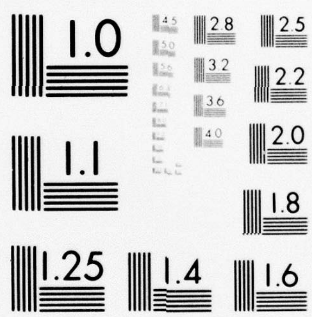

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

```
CHOOSE ONE OF THE FOLLOWING OPTIONS :

    1  INITIALIZE PARAMETERS (MUST BE PERFORMED FIRST)
    2  PERFORM  0 REFERENCE  - DELTA T
    3  PERFORM  0 REFERENCE  + DELTA T
    4  PERFORM MRT WITH NEXT TARGET
    5  PERFORM MRT WITHOUT VIDEO SAMPLING
    6  REPEAT MRT WITH SAME TARGET
    7  RE-SAMPLE BIOMATION
    8  TEST SAMPLE VIDEO WITH BIOMATION
    9  END PROGRAM

 9
---
 @
```

REFERENCES

1. Goodman, J. W., Introduction to Fourier Optics, McGraw-Hill, 1968.

2. DeVelis, J. B. and G. B. Parent, Jr., JOSA, 57, 1486 (1967).

3. Lloyd, J. M., Thermal Imaging Systems, Plenum Press, 1975.

4. A Digital System for the Characterization of Electro-Optical Sensors, AFAL-TR-75-58, Systems Research Laboratories, Inc., April 1975.